THE ADVANTAGES OF THE LATEST CUTTING MATERIALS.

Paper presented to the Institution, Glasgow Section, by W. Muirhead, A.M.I.P.E.

THE subject before us to-night is one on which much attention has been focused during the past few years and this makes the task you have set me rather difficult. I am sure the discussion which follows this paper will form the most interesting part of our proceedings this evening, and I am equally certain as I look at the audience that your remarks will not be confined solely to the *advantages* of the latest cutting materials.

At the outset it is necessary to define what shall be included under the heading—latest cutting materials. When considering this point I was surprised to find that 18 per cent. tungsten H.S.S. was made in this country as far back as 1905, twenty-eight years ago, and with the addition of vanadium in 1909. We cannot include this as a new cutting material but I think it forms by far the greatest percentage of cutting tools used to-day.

The combination of toughness and hardness found in this material makes it the best cutting medium we have for many of our machining operations. However, for the purpose of our consideration this evening we will take the following as representing latest cutting materials:

(1) Super high speed steels, containing usually about 22 per cent. tungsten.
(2) New types of stellite.
(3) Cemented carbides of titanium, molybdenum, etc.
(4) Cemented tungsten carbides.

Most of us probably started our training with carbon steel tools which were only capable of cutting speeds of 15 to 20 f.p.m. and it is a remarkable fact that no cutting metal, however new or revolutionary has yet succeeded in entirely ousting this material from the field of cutting tools. This goes to prove that no one cutting metal or alloy combines in itself all the advantages of its competitors, and one of the tasks confronting engineers in large factories to-day is the application of all the various types of tools now available to the work on which they will be most productive and economical.

January 18th, 1934. (*Vol. XIII, No. 6, June, 1934*).

In this connection, one of the greatest dfficulties lies in determining what effect the affinities of metals will have in selecting a tool for a certain job. This condition occurs in practice as if there were some residual magnetism in a particular tool which attracts the cuttings from certain steels during the process of machining, causing friction, cratering, and wear, whereas the same tool may operate on another steel as if a repelling action were taking place, resulting in less abrasion and a longer life for the cutter. I noticed an article recently in *Machinery* in which the term " surface energy " is used to describe the forces which make the atoms combine to resist abrasion.

Here is rather a remarkable case, brought to my notice within the past few weeks, and which I think can only be explained by the foregoing remarks on the affinity of certain metals for each other. The support for a centreless grinder was faced with tungsten carbide. Formerly the support was made of high speed steel. It was found, over a period of months, that the production between grinds was not any better with the tungsten carbide support than with the high speed steel. Both supports produced about 115,000 parts approximately $\frac{1}{4}$ inch diameter by $\frac{3}{4}$ inch long in free cutting mild steel between regrinds. It is probably for this reason that a certain tool may be excellent for machining $3\frac{1}{2}$ per cent. nickel steel, proving better for this particular application than another, which is supposed to have the same physical characteristics, made by a firm of equally good repute. Try these two tools on a 40 ton carbon steel and exactly opposite results may be obtained. These remarks apply to all materials, including cemented carbides.

During recent years one development which can be claimed as a general advantage with all the latest cutting materials is the use of butt welded or tipped tools. This has been brought about by their high price making it prohibitive to use these materials in solid form. The introduction of this feature has some very definite advantages which are sometimes overlooked :

(1) The yearly cost of tools is probably cut down considerably.
(2) No forging is necessary.
(3) Tools are usually in a much better cutting condition as the heat treatments have all been carried out by the makers in properly controlled furnaces.
(4) The shape of each tool has been designed to give the maximum efficiency under normal working conditions. A workman may find it necessary to alter the shape of a tool but this is more often done to satisfy prejudice and preconceived ideas than to effect any improvement in cutting.

The newer high speed steels have increased the range of cutting speeds and made possible the machining of metals on which the older grades could not be used economically and in some cases *not at all*.

It must be borne in mind that for many machining operations high speed steel has no equal and the advances which have been made in hardness or composition have effected considerable improvement in production. An outstanding example of the superiority of high speed steel is in drilling. This field of usefulness has not yet been touched to any extent by the cemented carbide tools, although in Germany drills have been developed which can utilise tungsten carbide to advantage on cast iron and cast brass. Tools for milling, tapping, and screwing are very largely confined to high speed steel, and these operations have been speeded up during the past few years by the improvements which metallurgists have been able to make, not only in hardness but in increased resistance to the abrasive action of cutting, by combining metals to make special alloys.

Stellite has been used by most of us for many years but the newer grades are not so well known. Considerable advance has been made, and for taking initial cuts on heavy forgings a combination of speed and feed can be used, which in some cases gives a more economical production than any other cutting tool. An example recently brought to my notice was the following:

Material being cut	...	Rough forging 40 ton steel.
Depth of cut ...	...	$\frac{3}{8}$ inch.
Cutting speed ...	...	90 f.p.m.
Feed	...	$\frac{1}{8}$ inch per rev.
Machine	...	New high speed centre lathe.

We now come to consider the most important group of the latest cutting materials—cemented carbides. The introduction of these tools has resulted in more careful thought and greater investigation into the art of cutting metal than ever before. These are now generally accepted as the finest medium the science of metallurgy has given us for certain machining operations on cast iron, cast brass, and many non-metallic materials. Their application to the machining of steel, while not so universal as in the case of cast iron and brass is extending rapidly, being governed largely by the progress of design in machines specially built to utilise their peculiar cutting properties.

Cemented Titanium and Tantalum Carbides.

One of the very recent developments which I think will be of interest is the type of tool for bar turning operations, with or without roller box. The shank material is hardened high speed steel, formed to act as a chip breaker. The five degrees side angle serves to control the chips, so that they drop away consistently on the cutting side of the tool. The tip is fixed in position with a special alloy and great care must be used in brazing, to ensure that the temperature of the furnace is carefully controlled. If a certain temperature is exceeded, strains are set up which may crack the

tip before the tool is put into service. One of these tools has been in use since October 6th last and, over a week's test, the performance is as follows:

Titanium Carbide:

Machine	... ...	Combination turret lathe.
Material	... ...	Steel 50 tons tensile.
Cutting speed	... ...	140 f.p.m.
Feed	... ...	72 c.p.i.

One regrind per day-and-a-half.

High Speed Steel:

Machine	... ...	Combination turret lathe.
Material	... ...	Steel 50 tons tensile.
Cutting speed	... ...	100 f.p.m.
Feed	... ...	72 c.p.i.

Three regrinds per day.

The tantalum carbide tools give an excellent finish on steel when using an exceptionally high speed, fine feed, and light cut.

Cemented Tungsten Carbides.

The advantages of these tools are many and we shall endeavour to deal with them in the order of importance. Some of the points will apply to cemented carbides generally.

1.—*Greatly Increased Cutting Speeds, resulting in Lower Production Costs.*—This forms by far the greatest advantage possessed by this group of cutting tools and the savings which can be effected in this way are very considerable. Assuming the use of old machines in reasonable condition, the reduction in floor to floor times on general work of cast iron and brass is, on an average, 33⅓ per cent. With new machines specially designed. this percentage figure is considerably increased and even on old machines I have known it be as high as 75 per cent., depending of course on the proportion of handling to cutting time. In reckoning savings made some people fail to take oncosts into account and many of the comparison tables published are so involved as to be quite confusing to the person who may be primarily responsible for the use of the tools. In allocating oncosts, there are three widely used methods:

(*a*) Rate per hour, which is applied to each machine individually, varying in accordance with the type, horse power, first capital cost, floor space occupied, etc. This may be 2s. 6d. to say 10s. per hour.

(*b*) A percentage on labour charges, usually not less than 150 per cent. and in some cases as high as 300 per cent.

(*c*) A combination of these two methods.

It is true, of course, that oncosts are increased by adopting expensive tools, but this is very small in proportion to the savings effected by their use.

There is a prevailing misconception that with the use of the new tools power charges go up out of proportion to the work done, and that oncosts are increased in this way. This is entirely erroneous and it can be taken as an axiom that the power consumption is directly proportional to the metal removed. I have noticed also that in making allowance for depreciation, machines specially designed to utilise the fast cutting metals are depreciated on paper much more rapidly than the older types. This idea requires modification, as the newer machines have much lighter loads imposed on slides, etc., than the older types, which had to withstand heavy strains when taking hogging cuts.

Take as a very simple example of what is meant here, a spindle which is to be machined from bar stock four inches diameter. The material is 40 ton steel. On a modern centre lathe this would be machined by taking the full depth of cut from "A" to "B", i.e., ½-inch at a cutting speed of 382 f.p.m. and a feed of 144 c.p.i., using a titanium carbide tool. When cutting under these conditions much less heat is generated in the work and very little expansion takes place between centres. This results in an excellent finish being left for subsequent grinding. By the older method it would be necessary —using high speed steel—to turn a band to run in a stay or steady rest and instead of finishing each diameter at one pass, probably three would be required—the first to take a roughing cut, using a feed of $\frac{1}{8}$ inch per revolution; a semi-finishing cut; and finally a scrape. In this latter method far more strain is imposed on the sliding parts of the machine than when using a high speed and fine feed. In this case the cutting load is largely radial, whereas with the newer practice the load is almost truly axial, resulting in a more accurate workpiece being produced.

2.—*Savings in Material.*—It is difficult to decide which advantage should rank next in importance. I have taken savings in material as the next point for consideration as I believe it is often overlooked that economies can be effected in this direction. In this connection it should be realised that cuttings from cast iron have very little value and every ton of material put into castings unnecessarily makes for added costs. The days when we had to leave "something on to get under the skin" have passed. The same remarks apply to cast brass.

This point is brought out clearly where Bailey wall furnace blocks are being machined. These blocks of cast iron are used to form the inside walls of a certain type of furnace. The radius portion on each size must be machined, so that the blocks conduct heat more readily to the tubes around which they are built. They are required in large quantities and it is usual to have a steady production of 2,000 per week. Until a year ago these blocks were ground by hand, the workman using light pneumatic grinding machines with cone shaped

grinding wheels. This method of lining furnaces originated in the United States and after spending much money on experimental machines the Americans came to the conclusion that no more economical method of doing this work could be evolved than the hand grinding already referred to. One mode of machining, which seems at first sight an obvious way of dealing with the job—form milling—has been tried out exhaustively—not only in America but in this country, at considerable expense to the machine tool makers concerned. These experiments ended in failure, for the simple reason—*and that is the point I wish to emphasise*—that the cost of adding metal to allow the form cutters to get below the sandy surface of work, was considerably more than the total labour cost involved in grinding. The figures are : Cost of grinding (labour only), 1s. 1d. per dozen blocks ; Cost of adding $\frac{1}{8}$ inch in thickness to the radius on each side of the blocks, 2s. per dozen blocks.

A simple method of machining these blocks, using tungsten carbide tools, was developed in Scotland about a year ago and has proved one of the most successful applications in my experience. Two snout boring bars are mounted side by side—one running clockwise, the other anti-clockwise. It has only been necessary to add $\frac{1}{8}$ inch of metal to the castings, not that this effects the cutting properties of the tools to any great extent, but mainly to facilitate setting and to ensure that each side of the casting is cleaned up. The working conditions, production, etc., are as follows :

(1)	Material	Cast iron.
(2)	Cutting speed	200 f.p.m.
(3)	Intermittent cut ...	$\frac{1}{8}$ inch deep through hard surface of material.
(4)	Feed	48 c.p.i.
(5)	Cutter bars	3 inches diameter overhung 12 inches from front bearings of machine.

One man works two machines.

Production	50 per hour, 400 per day.
Labour cost	2½d. per dozen blocks.
Cost of tools	52s. per set, comprising four tools for one machine.
Average life of tools between grinds	One day.

3.—*Improvement in Castings* (*Cast Iron and Brass*).—The next point is closely allied to the foregoing, namely, the improvement in castings, consequent on the introudction of these tools—particularly the wearing surfaces of machines which can now be made much harder, either by a process of chilling or alteration in mixture.

Machine tool makers have been able to increase the hardness of slide ways from 200 to 230 or 250 Brinell. In the same connection these tools have had a refining influence on the design of machines

generally. An instance of this is the fine boring machine which has been put on the market within the past two years. This fine boring process with tungsten carbide tools has been applied mainly to finishing the bores of engine cylinders and the surface left is so good that grinding and honing are sometimes dispensed with. It is also well known that ball and roller bearings have had to be applied to many machine tools in order to obtain the very high cutting speeds required to use these tools efficiently. Whether this is an advantage or not may be open to question, but I am sure the ball bearing manufacturers at least, will consider this a step in the right direction.

4.—*Length of Life between Grinds.*—The next advantage I wish to mention is a very important one—length of life between grinds. This is particularly applicable in the case of cast brass and several firms use large quantities of tools on brass. One firm in Scotland, engaged in the manufacture of brass pipe fittings—T pieces, unions, special couplings, etc.—has a large number of capstan lathes engaged continuously on this class of work. One of the directors arranged for a time study to be taken to ascertain the amount of lost time involved, due to grinding high speed steel, and found that this worked out at forty-five minutes per man per day. Each machine has a set-up of five or six tools and the time is quite reasonable when you consider that removing the tools, grinding, and resetting to size is included. Tungsten carbide tools were applied to this work, including a number of form tools and combination tools for reaming, chamfering, and facing, which last on an average eight weeks before regrinding is necessary. Even then only a very small amount is ground away—normally not more than .005 inch—from each tool. Except for accidental breakages these tools will last for many years before being worn out.

The foregoing remarks apply to old machines, but a recent development has been the introduction of a number of capstan lathes which can give a speed of 3,000 r.p.m., to take fuller advantage of tungsten carbide tools. At the moment, experiments are being carried out here in the application of a set of geometric chasers tipped with cemented tungsten carbide, so that the machines can be run at a constant speed. In the first test the chasers operated successfully for about four hours, but at this point one of the tips came off. There is little doubt that this new development will eventually be successful when the initial difficulties have been overcome. Single chasers have been widely used for several years on the screwing of brass.

5.—*Form Tools.*—This is one of the most successful applications of tungsten carbide. The chasers already referred to are really form tools, made to a very high degree of accuracy.

The short life between grinds and the difficulty of maintaining accuracy limits the use of high speed steel form tools on cast iron

and cast brass, due to the abrasive nature of the material. A form tool in tungsten carbide will maintain its shape for months without regrinding under certain conditions, and it is advantageous to extend the use of this principle wherever possible.

6.—*Taking Final Sizing Cuts.*—Next in importance, I think, comes the advantage obtained when taking final sizing cuts on various classes of work. One very interesting example of this is the boring of stern tubes for propeller shafts. These are brass castings and may be up to 20 feet long. The bore as cast is usually eccentric to the outside diameter of the tube.

A cutter head with three tools is generally used for the boring operation and when using high speed steel in an eccentric bore it is quite common to regrind after every three of four feet machined. With the use of tungsten carbide a number of liners can be machined without having to grind the tools. On the finishing cuts it is a very great advantage to obtain a parallel bore, without the necessity of regrinding several times. The overall saving in time on work of this description may be easily 50 per cent. and in some cases more. It should be noted that the machines used in this work are quite unsuitable for high speeds and the saving is effected by tool life between grinds and the facility for taking finishing cuts without having to make several passes through the liner.

Reaming also comes under this heading and some very interesting work is being done in this direction. Two blade reamers are being very widely used and bores can be held to .002 inch in this way, reasonable periods being obtained without adjustment or grinding. The most outstanding development has been in the finishing of comparatively small bores $\frac{1}{2}$ inch, $\frac{5}{8}$ inch, $\frac{3}{4}$ inch diameter, etc. One firm has found it much more economical to finish such bores in unhardened material by reaming with tungsten carbide tools than by grinding. The maintaining of size for long periods is the main advantage gained. On the reaming of valve guides the life between grinds is six times as long and total life about eight times that of high speed steel. Probably the most outstanding example of finishing cuts is that already referred to, i.e., fine boring of cylinders which could not be done except for the latest cutting materials.

7.—*Simplifying Certain Machining Processes.*—One of the most outstanding examples which comes under this heading is the turning of chilled iron rolls. Until recent years the established method of turning chilled iron rolls was by block tools which were fed into the hard surface of the roll, either by a hand operated screw or a wedging action. The cutting speed was three to five feet per minute for the hot plate rolls and two feet per minute for the very hard rolls used in paper machinery and chocolate squeezing plant.

The turning of these rolls was at one time a special trade, but this has now been reduced to an ordinary machining operation.

One firm in Scotland has converted a double ended roll turning lathe with centre drive to a sliding and surfacing lathe, by placing four lead screws along the bed, two on either side of the centre driving head, and adding cross slides to both sides of the machine. The cross slides obtain their drive by suitable gearing from the lead screws and in this way nine cutting tools are made to operate simultaneously at a cutting speed of 12 feet per minute, i.e., six times the former speed. In this class of work cutting forms so large a proportion of the total time that the saving over the older method is as much as 50 to 75 per cent. In machining hollow cylinders of chilled iron it was formerly common practice to cast on false ends which were used merely to support the work during the turning which was done with block tools between centres. These cylinders are now machined in the ordinary way and a considerable saving in metal effected.

Another instance of the return to simple machining methods is seen on the Magdeburg chip-flow lathe in which a single tetanum carbide tool is used to produce results similar to those obtained on multi-cut lathes. I have previously referred to the successful use of the brass finishers' lathe—a simple type machine on which excellent production is obtained by the use of these tools.

8.—*Cutting metals hitherto unmachinable or which could only be machined with great difficulty.*—These include the following. LO-EX aluminium for pistons; 12 per cent. manganese; high silicon cast iron; 12 per cent. nickel; hardened high speed steel; hardened cast steel; push bench dies; hardened cast iron liners 450 Brinell.

For machining hardened high speed steel and cast steel the tools used must be of a specially hard grade of tungsten carbide, ground to a definite profile and with suitable clearances. Any attempt to use standard tools for this particular purpose is bound to meet with failure.

Turning.—When turning hardened high speed steel about 680 Brinell a cutting speed of 72 feet per minute is used. The chip comes off in an almost molten condition and leaves a very highly polished surface.

Planing.—Much the same type of tool is used for this operation. In both turning and planing the depth of cut should be not more than $\frac{1}{8}$ inch and the feed kept as fine as possible.

Drilling.—For shank material high speed steel should be used with a large core diameter to avoid vibrations during the drilling operation.

9.—*Use for Wear Resisting Surfaces.*—Important advantages have been obtained in this direction. The first application I will

mention is that of cylindrical gauges. In one particular case, a plug gauge, the total tolerance allowed is .0005 inch. In normal production .00025 is worn away in one week, when made of the best wear resisting steel and the gauge must be replaced. One of these made in tungsten carbide has been in operation for 50 weeks and only .0001 inch of wear has taken place. Gauges made from this material are practically unaffected by temperature variation (the expansion of tungsten carbide is about one five millionth part of an inch per degree Cent. rise in temperature) and so it is an excellent medium for making standard reference gauges.

Another instance is that of " V " blocks in which small circular spindles revolve. When made of steel they gave a production of 68,000 parts. 3,500,000 parts have passed through a similar block made of tungsten carbide and it is estimated that it is good for a further 2,000,000.

10.—*Making Possible the Machining of Small Quantities of Castings (Cast Iron and Cast Brass) on Automatic Chucking Machines.*—The successful application of chucking automatics to the machining of small quantities (15, 30, 50 off, etc.) which are recurring, depends almost entirely on two factors :

(*a*) The ease with which the mechanical motions of the automatic can be changed over to meet new conditions affecting cutting speed, feed, length of traverse, etc.

(*b*) Tool life between grinds.

The first item is outside the scope of this paper, except perhaps to say that machines of older design bear no comparison with the modern chucking machines in this respect. It is with item (*b*) that we are mainly concerned. The definite advantages offered by the use of these tools are :

(1) Special tool blocks carrying a number of tools can be made up and if the machine is operated at a reasonable speed long life will be obtained before any tool requires grinding. In practice this means that 200 or 300 parts representing perhaps 10 to 15 batches of 20 off can be put through the machine without grinding of tools.

(2) The relation of various diameters or recesses to each other remains nearly constant throughout the whole batch of castings, requiring a less rigid system of inspection.

(3) Form tools can be used to great advantage cutting out multiplicity of single tooling operations which would normally be done by hand on a turret lathe. An example which comes to mind is pump impellers which are being dealt with very successfully in this way.

11.—*Drilling of Brick, Concrete, etc.*—Two instances, I think, will be sufficient to emphasise the advantages of this particular application :

(1) A local firm in reconstructing a boiler recently found it necessary to drill a large number of holes in firebrick material. The holes had to be fairly accurate in size. If made larger than necessary too much heat was allowed to pass through the opening and if too small breakages took place, due to expansion of the tubes. Tungsten carbide drills were applied with great success.

(2) A building was recently being reconstructed and it was found necessary to drill holes through 18 inches brick walls for electric conduit tubing. This also proved an excellent application.

Drilling holes in concrete floors for foundation bolts, etc., with these tools is a great advantage over the older method of using a rock drill or chisel.

Although wonderful advances have been made in the art of cutting materials by the use of non-ferrous materials, finality has not yet been reached. Metallurgists and chemists in many parts of the world are carrying on researches which will one day result in even greater advances in the cutting of metals.

Discussion.

MR. W. BUCHANAN: With regard to Mr. Muirhead's reference to tungsten carbide as against high speed steel, I believe the later mixtures of tungsten carbon are an improvement. Tapping and screwing. I do not think there is much improvement in the ordinary steel used for taps and dies, but there is a big difference in the grinding of threads. They give better clearances and pitches and I think that is why we get higher speeds from our taps and dies. Tipping of high speed steel shanks. I should like to hear more of the method by which it is done. We know it is difficult to put a Wimet tip on to a high speed steel shank. Another point. He refers to the saving of material due to the use of tungsten carbide tools. I think that that point only refers to quantity manufacture because, where you have only one or two parts to make, the extra cost of the pattern to ensure accurate castings would be far more than any saving of material.

MR. MUIRHEAD: Regarding super high speed steels, some improvement lies in roller box turning. I think 22 per cent. tungsten high speed steels used for roller box work are a considerable advantage over 18 or 14 per cent. So far as tapping is concerned I am inclined to agree generally, but in the tapping of brass and cast iron there is a definite advantage, although this may not be so evident when screwing steel. Regarding the tipping of high speed steel shanks, a special copper nickel alloy has been developed for use as a fixing medium. When using this material great care must be taken to see that the furnace temperature is controlled between 1,180° C. and 1,200° C. If the temperature rises above 1,200° C., strains are set up which are sufficient to crack the tip before it is put into service. If the furnace is properly controlled you can, with this material, make a success of tipping tungsten carbide to high speed steel. Saving of material. I am in agreement with his remarks. It would not apply to single castings or small quantities. It is only evident where you are dealing with large quantities, and I think the instance I gave—2,000 per week—comes under this heading.

MR. MCFARLANE: One of our difficulties up to the present has been ring gauges for small work and getting them sufficiently accurately ground prior to any lapping operation. If they are not accurately ground then of course the lapping operation is almost hopeless. Mr. Muirhead knows the difficulties we have had up to the present, but I can assure him we have not given up the ghost in the matter and we are going to have another try.

One point on the economical side I am apt to question. Regarding the Bailey blocks was I correct in assuming that Mr. Muirhead said

by adding $\frac{1}{8}$ inch for machining on to those two cylindrical faces it was going to increase the cost of material for 12 pieces 2s. or 2d. per piece? I have made a calculation and find when the cost of iron is 1½d. per lb. and there is no allowance to be made for return and use of a certain percentage of the cuttings it comes to 1¼d. per casting.

Can Mr. Muirhead tell me whether it is possible to get bakelite laps impregnated with diamond dust as small as $\frac{1}{4}$ inch diameter?

MR. MUIRHEAD: The development of tungsten carbide for gauges has been, I should say, entirely due to the initiative taken by his company, under Mr. McFarlane's supervision, and excellent results are being obtained. It was this particular example I referred to in my paper. The finish grinding of these gauges had to be left for his company to do. Regarding the cost of adding metal to Bailey blocks, it is a question of simple calculation. The amount of material involved is about 1¼ lb. per block and, basing the calculation on cast iron at £15 per ton, it works out at roughly 2d. per block. Mr. McFarlane asked whether it was possible to make diamond loaded bakelite laps ¼ inch diameter. This is quite possible and the diamond dust can be graded coarse or fine. On the Continent a firm is making a grinding wheel of diamond dust. It removes the tungsten carbide very quickly and is a commercial proposition.

MR. KIRKWOOD: Mr. Muirhead made a point at the beginning of his paper which I think is extremely important and which is sometimes overlooked. He emphasised it but I do not think many of us appreciate its full significance. That is in dealing with tipped tools in general, the heat treatment of the tool after it has been formed to shape is outside the hands of the user. There are a number of firms who have proper heat treatment facilities, but I think I am right in saying that the bulk of users have only crude facilities such as the blacksmith's fire which, in dealing with alloy steels is useless. It is a considerable benefit to the industry if any man, having a machine shop, can go to a factor and buy a tool of proper shape, properly heat treated, and ready for use. In connection with the direction of thrust on the tool, the thrust on a tungsten carbide tool is more or less axial to the lathe whereas on the older type of tool it is radial and causes a heavier load on the bearings. The point of having a negative top rake for turning very hard metal would seem, at first sight, to be entirely wrong, but we have his assurance that that is the correct rake for the job, and I think if we follow the logical change in rake from the cutting of wood down to aluminium and steel of normal hardness it does not seem ridiculous that we should have negative rake. In connection with gauges I would join issue with Mr. Muirhead on the advantages of having a small coefficiency of expansion. I agree he said it was desirable for reference blocks, but for shop gauges surely it is an advantage to have your gauge coefficient of expansion as nearly as possible the

same as the component which you are gauging so that you are independent of shop conditions. Those of us whose misfortune it is to machine aluminium know that you can get vastly different results in winter than in summer when working with steel gauges. Where the limits are close this may be sufficient to make all the difference between a satisfactory and unsatisfactory job.

MR. MUIRHEAD: On the question of tipped tools Mr. Kirkwood agrees with what I said, but there is one point I want to emphasise. As the tungsten content increases, the hardening of high speed steel becomes a more critical operation and while you may deal fairly successfully with 14 per cent. tungsten in a blacksmith's fire, 22 per cent. cannot be properly hardened in this way. Direction of thrust on the tool: I do not think comments are necessary. Nor does the question of negative top rake for cutting high speed steel call for any comment. Regarding gauges. I am very glad I said "for reference gauges only."

MR. PLATT: Referring to the material used for brazing. Originally, the brazing material was a soft brass compound requiring a low temperature, but as time has gone on, the brazing material has got harder until we are using copper now which requires a high temperature. During this change the type of fractures of the Wimet have changed. Originally all the tools which came in for regrinding were worn, but now we find that the fractures which have occurred are fractures in the Wimet itself, going back into the copper all the time. What is the effect of overheating Wimet over 1,200 degrees C.? That may have some bearing on the question of the copper nickel bonding material. I think that now the fractures in the Wimet are generally occurring right through the Wimet and cutting away part of the copper. Can he place in order—soft brass, hard brass, and copper, as brazing mediums for general purposes when you have only got an ordinary gas furnace? Could he give us any definite ratio between cutting pressure of the tool for similar shaped tools of high speed steel and Wimet? Is not nitralloy for light cuts approaching the form of Wimet with considerably less expense? Using spot facing cutters as illustrated, can he give us any figures relative to the cutting pressures? In my opinion the cutting pressure on spot facing cutting with Wimet is considerably greater than with all high speed steel.

MR. MUIRHEAD: Materials for brazing. I would not describe brass as a softer metal than copper. Brass can be used to advantage if the job is a very difficult one. What I have in mind is an intricate milling cutter or reamer with inserted teeth. It is difficult to get the copper to flow evenly, and under these conditions, with a gas furnace, brass might be used to better advantage. Copper is, I think, the best medium we have for brazing. To melt the copper you must have a temperature of 1,180 degrees C. or perhaps a little

higher, 1,200 degrees C. This gives a stronger joint than with brass, because a metal with a higher melting point is used. This applies particularly if the tool is likely to be overheated, due to difficult working conditions. There is also much less tendency for the tip to come loose than when using a brass with a melting temperature of 900 degrees C. Another important point is that copper has a cushioning effect in fixing the tip to the shank. This has reference to the various coefficients of expansion. You are dealing with the shank, which may be .5 or .7 carbon—the copper, forming the medium for the joint—and the tungsten carbide. The expansion of tungsten carbide is less than that of any known metal. It is approximately half that of invar. The expansion of steel and copper is well known. When you join these three metals together, you get strain set up and unless the brazing medium allows for some cushioning effect between the two metals, you are apt to have cracking. It is because of this limitation iron cannot be used as a brazing medium, as it allows no cushioning between the tip and the tool. I know one firm who brazed 12 tools with a well-known compound containing iron and found afterwards they had all cracked. I have no hesitation in saying that copper is the best medium we have for fixing tungsten carbide tips in position. For a considerable time we found great difficulty in brazing tungsten carbide to high speed steel cutters where we wanted extra support for the tip and where the size of the tool would not allow us to use .5 carbon steel. This has now been made possible, however, by using the copper nickel alloy already referred to.

Regarding overheating. You will not damage tungsten carbide below 1,300 degrees C. The actual temperature used for the sintering process varies from 1,600 degrees to 1,800 degrees—that is the actual heat through which it passes. You can go considerably above 1,200 degrees C. before you disintegrate the material. Even at 1,200 degrees C., however, there is danger of oxidisation taking place and your furnace should contain a reducing atmosphere. Generally speaking, I should say pressure is always less with tungsten carbide than with high speed steel, but in this particular instance I think Mr. Platt is speaking from experience, and in that case I cannot join issue with him. Regarding nitralloy one serious drawback is that the maximum depth of hardness you can get is about 30/1,000ths, so I am afraid the life of the tool would be very short, unless used in some application such as a reamer, where this depth of hardness would be satisfactory.

MR. BUCHANAN: In almost every case the tip has been manufactured of Wimet and brazed in to other materials. There seems to be a great deal of difficulty in the treatment afterwards or due to the brazing cracking and such like. Mr. Muirhead will know that stellite can be deposited by the oxy-acetylene blow pipe on

carbon steel. We have to use high speed steel for parts which are used for cutting coal, etc., and we have found that the stellite deposited on .35 carbon steel has been very efficient. Does he know of depositing high speed steel with electric arc from the rods on the market on .35 carbon steel tools? Also that the cost compared with the high speed tip or tool is only one-sixth or one-fourth against these tipped tools. Has he any experience of tools working with electrically deposited alloys?

MR. MUIRHEAD: The difficulty in depositing any material, whether it is stellite or high speed steel lies in this, that in both almost invariably a gaseous structure is formed. I saw an attempt recently to deposit high speed steel and it was shown to me where a number of blow holes were evident through the metal, which made it quite unsuitable for that particular application. I think the same remarks will apply to stellite. The application which Mr. Buchanan has in mind, tipping coal picks, is rather an exceptional one. The tool must stand abrasion but the pressure is not very high and, in this case, I know it is a successful application but I do not think the stellite manufacturers would recommend it to be used as a cutting tool, after being deposited by an oxy-acetylene flame.

MR. HARDAKER: Has he any experience of tipped tools for machining material having an acid content? Regarding Mr. Kirkwood's reference to gauges, I have an instance of machining a rubber flexible coupling, the outside of which is soft and the inside is hard. Plus and minus tolerance was .002 inch. We had considerable trouble in gauging due to heat. Could Mr. Muirhead suggest a suitable material where we would not have the same trouble of coefficiency of expansion affecting it the same way?

MR. MUIRHEAD: I am sorry I cannot give you actual figures from memory, but I can say definitely that tungsten carbide is much more resistant to acids than any other cutting material. I do know that a firm down south use tungsten carbide cutters which are suspended in an acid solution.

Machining rubber. As a matter of fact tungsten carbide is widely used on this material but so far as the gauges are concerned I cannot help you. I think Mr. McFarlane may be able to answer that question.

MR. TAYLOR: I do think he has been very conservative about the 200 feet per minute for cast iron, and I think he knows we can do better than that. Another point is where he speaks about having tools for certain jobs and putting them away after being used, and putting them back on the machine in the same position. That would be all very well in a place which had a limited number of components, but in a place which is handling 5,000 or 6,000 components the idea is to try and keep as many standard tools as possible to do the work so that they can be used over and over again for various

operations. You could imagine the number you would require if you had Wimet tools for about 5,000 or 6,000 operations multiplied by six for the various other parts they had to do, and I think you would have to be very careful before you decided to do that.

MR. MUIRHEAD: The question raised is an interesting one, but after all it is simply settled by proportion. While it is true to say you may have 5,000 operations in a shop, you may only have four or five automatics, and of all your work you may only have five per cent. suitable for these machines. It is not a question of making groups of tools for every job in the place but only for work which can be done on chucking automatics. The comparison being made is with tools which would lose their cutting edge very rapidly and therefore the expense of making a block to contain four or five tools would not be justified because more time would be lost in regrinding than would be gained by the group method. If you can get these tools to stand up without grinding for 200 or 300 parts it is a very economical proposition which I know, from experience, works very well indeed.

MR. KERR: I was under the impression that tungsten carbide tools were liable to flake where the material was not uniform either in shape or structure of material. He illustrated a case to-night where the material being machined was not uniform in shape, and in one instance he quoted where tungsten carbon tools were being used for the drilling of foundation holes where it is quite possible that the material was anything but uniform. Is it economical to consider the use of these tools where you cannot be sure definitely of the uniformity of the metal being cut?

MR. MUIRHEAD: The point raised has been fully dealt with in the paper, slides, and film. I presume Mr. Kerr means intermittent cutting when he refers to the job not being uniform, and if the material is low in tensile there is no difficulty whatever. Where you are dealing with high tensile materials, including steel, you will experience greater difficulty, but provided the material is of cast iron, brass, stone, concrete, etc., you would not have any difficulty. I can understand if you were drilling through a concrete foundation with inserts of granite chips or something of that nature, it might not be so easy. These inserts sometimes move and jam the cutter. In cast steel we often get small bullets or hard spots which do not cut with the material in some cases, but turn in the hole and break the cutter.

MR. GEDDES: It was mentioned that the machining of walnut presented certain difficulties. In this respect I may have been fortunate. What I should like to know is: Can Wimet be applied to *lignum vitae*? I have had difficulty with *lignum vitae*, and I should be indebted to him if he would state whether Wimet would be an advantage here.

MR. MUIRHEAD: The wood referred to was Australian walnut. It appears this particular tree grows very rapidly and sucks up sand from the soil. I have heard it stated that it is not a commercial proposition to machine this wood with ordinary carbon steel tools. Reference was made to this in an excellent paper given before the Institution by Messrs. Garnet and Field. Regarding *lignum vitae*, this is definitely a very good application for these tools and the same applies to teak and ply-wood. The planing of wood with rotary cutters has now been successfully accomplished in this district with a considerable reduction in cost. It has only been possible since we have been able to get a keen edge on the tungsten carbide, by means of bakelite wheels impregnated with diamond dust. This enables us to get the knife edge normally to be found on wood-working tools. Woodworking spindle machine cutters can be made in tungsten carbide and used successfully.

Machining ply-wood. The cement which binds the various laps together is very abrasive and routing cutters are now being made in tungsten carbide. I can give you an actual instance where carbon steel tools last for three to four hours and about $\frac{1}{8}$ inch is worn off in that time, but the tungsten carbide lasts for at least fourteen days without any appreciable sign of wear.

MR. RAMSDEN: Can Mr. Muirhead state whether the pressure on the tool is increased, in about the same proportion as the metal removed per minute?

MR. MUIRHEAD: The horse power remains in direct proportion to the metal removed. This point was dealt with in one of the slides.

MR. WRIGHT (Section President, presiding): I should like to welcome the large gathering this evening. Regarding Mr. Muirhead's paper I think we have plenty of evidence that he thoroughly understands his subject irrespective of the fact that he is interested especially in one particular brand of material. I think he has been a little confined in his paper with regard to the variety of cutting materials. Such things as diamond-cutting and the latest regrinding wheels should have been included in a paper on the latest cutting materials. They are included in this subject. However, I feel we can excuse him because it appears what he has talked about has been sufficient for one evening. The advances of cutting materials have been many but the advent of these materials has caused us to overhaul our plant to cater for the speeds necessary to deal with these materials, and, if for that reason only they have served a good purpose. Had we given the same amount of attention to our machine tools before the advent of these new cutting alloys, I do not think the discrepancies between the figures would have been so great.

A vote of thanks to Mr. Muirhead concluded the proceedings.

SOME SCIENTIFIC FALLACIES, PARADOXES, AND PECULIARITIES.

Paper presented to the Institution, Birmingham Section, by D.S. Anderson, Ph.D., B.Sc., M.I.Mech.E., M.I.A.E.

WHEN your committee invited me to deliver a lecture before this branch of your Institution I was rather at a loss as to what to choose for a subject. I was not in a position to deal with any aspect of production engineering but after some consideration decided that an examination of some of the current fallacious scientific beliefs might be both interesting and amusing. I have called them " scientific," not because they deal with scientific theories, but because I have selected those dealing with the physical properties of materials and excluded all literary and historical fallacies. Hard on the heels of fallacies come paradoxes and one can hardly separate peculiarities from paradoxes, and so the title eventually sorted itself out into " Some Scientific Fallacies, Paradoxes, and Peculiarities."

I hope, in the course of the evening, to tell you of things currently supposed to be true which are not, to show you things which apparently ought not to be true but which are, and to show you happenings which could certainly not be predicted by ordinary commonsense.

Once an idea gets spread abroad and continually repeated it is soon believed. It is amazing how credulous people are even in this scientific age, and when we remember that many of the fallacies I will mention to you are probably centuries old and that consequently one generation after another have grown up with them, it is not surprising that they are difficult to eradicate. Even to-day reiteration is accepted by the majority of people as a convincing form of argument and they will believe almost anything if sufficient people and newspapers say so. We are prone, nearly everyone is, to let our critical faculties lie dormant so long as the belief in question does not particularly affect us. We do not ask for proof nor do we make any attempt to apply even commonsense tests. In other words most of us are intellectually lazy and thus fallacies flourish.

Many fallacies are extremely foolish and stupid but not all can be regarded as coming within this class. Many of the scientific

December 20th, 1933.

truths of one generation are the fallacies of the next but it is not of such that I am going to speak. Such fallacies did at the time represent the result of an honest search for the truth and did represent the best interpretation that would fit in with the observed facts. The fallacies I am going to describe have become current due to scientific ignorance, mental laziness, or a combination of both.

Roughly speaking fallacies belong to two classes, fallacies of argument in which the error lies in the supposed proof, and fallacies of observation of perception in which the error lies in the observations from which the deduction is made, the line of argument being substantially correct. While all fallacies can be placed in one or other of those two categories I do not propose to divide them in this way. It will be more convenient to gather them into groups depending on the subject matter with which they deal.

Three of the oldest of all fallacies are perpetual motion, the philosopher's stone, and the elixir of life. No one nowadays believes in the philosopher's stone which was to transmute all metals into gold, or in the elixir of life which was to restore lost youth, but perpetual motion is still a hardy annual. Perpetual motion is, of course, quite impossible and no expenditure of ingenuity in the design of any machine will ever make it possible, but it is surprising how many people even to-day are still pursuing this phantom. Nearly all the supposed solutions fall into two categories, one using the multiplying power of levers, the other involving the action of supposedly unbalanced weights. In the first category the fallacy of the argument lies in the failure to realise that while a lever can multiply force it cannot multiply power. In the second category all the examples are the same in principle, namely, that a wheel is provided with an arrangement of balance weights of such a nature that the weights on one side of the wheel are held at a greater distance from the centre than the weights on the other. But this arrangement inevitably gives more weights on the side of the wheel where they are nearer the centre, and while there may be one or two positions in which the two sets of moments are not equal, this will merely cause some oscillation about an equilibrium position. No permanent rotation is possible. Other devices seek to make use of magnetic attraction but these are equally futile.

Nearly all mathematical fallacies are fallacies of argument, and some of the examples are quite interesting. To take a geometrical case, let $ABCD$ be a square.

Make $CE = CB$. Bisect AB and AE at right angles and let the lines meet in O. Join OC and OD. Compare the triangles OAD and OEC.

$$\begin{aligned} OA &= OE \\ OD &= OC \\ AD &= EC \end{aligned}$$

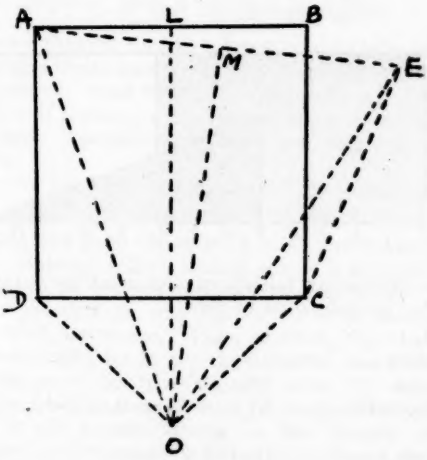
Therefore the triangles are equal in all respects and

$$\therefore \hat{ODA} = \hat{OCE}$$

Substract the equal angles *ODC*, *OCD* from each, then

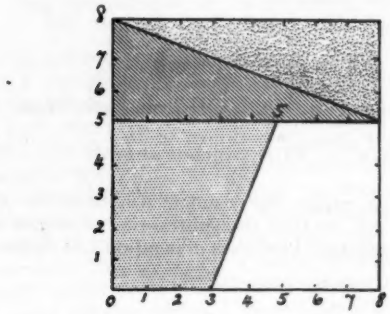
$$\hat{ADC} = \hat{ECD} \text{ which is absurd.}$$

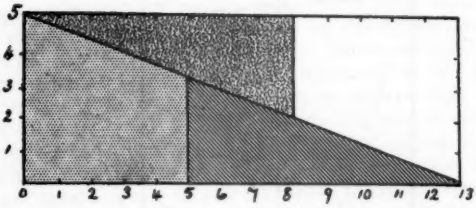
The fallacy is that in reality the point *O* will be so far away that *OE* will fall outside *EC*, so that the subtraction of angles cannot be carried out. All geometrical fallacies depend on bad figure drawing.



Another geometrical fallacy is that it is possible by compass and ruler to square the circle or trisect an angle. Dozens of solutions have been produced to both these problems and some of them are very close approximations indeed, but there is no exact construction possible for either.

A geometrical puzzle which one often sees is the apparent conversion of an 8×8 square to a 13×5 rectangle. The square is cut and pieced together again as shown. The fallacy, of course, lies in the fact that the diagonal of the rectangle is not a single straight line but is really a very elongated diamond shaped area equal in magnitude to one square.





There is an interesting fallacy of argument by which one may apparently be proved equal to two.

Let	$a = b$
then	$a^2 = ab$
also	$a^2 - b^2 = ab - b^2$
factorize	$(a - b)(a + b) = b(a - b)$.
	$a + b = b$
but $a = b$	$2b = b$
	$2 = 1$

The flaw in this argument is that it is not permissible mathematically to divide out by $(a - b)$ since $(a - b) = 0$ and $\frac{0}{0}$ is indeterminate.

One of the classic examples of fallacy of argument is that of Achilles and the tortoise. This fallacy was well known to the Greeks, but although they knew that it was a fallacy, I do not think that they knew where the flaw in the argument lay. The story runs that Achilles, the famous Greek warrior and athlete, challenged the tortoise to a race of 1,000 feet and conceded it a start of 500 feet. We will assume for simplicity that Achilles could run 10 times as fast as the tortoise, so obviously the tortoise had no chance at all. Argument, however, can be made to prove apparently that far from winning the race Achilles can not even

overtake the tortoise. The argument runs this way. While Achilles covers the first 500 feet the tortoise has gone 50 feet; while Achilles travels this 50 feet the tortoise travels five feet; while Achilles travels this five feet the tortoise travels .5 feet and so on. Thus Achilles never even overtakes the tortoise, the latter is always a little bit in front.

The fallacy is easily exposed if we write down the distances that Achilles has to cover and the time he takes to cover them.

Assume that his speed is 10 feet per second:

Distance to go, feet $500+50+5+\frac{1}{2}+\frac{1}{20}+\frac{1}{200}+\ldots\ldots$

Time to cover distance $50+5+\frac{1}{2}+\frac{1}{20}+\frac{1}{200}+\frac{1}{2000}+\ldots\ldots$

From this we see that his time to catch up the tortoise is represented by the sum of an infinite number of terms and the argument assumes that this is infinity. And therein lies the fallacy. The sum of an infinite number of terms of a converging series is not infinity but a perfectly definite quantity; in the preceding case it equals: $\frac{50}{1-\frac{1}{10}}=\frac{500}{9}=58\frac{8}{9}$ secs. At the end of that time, that is at a distance of $555\frac{5}{9}$ feet from the start, Achilles overtakes the tortoise.

There is an amusing fallacy arising out of a supposed argument between two Jews, an old Jew and his young employee. The young employee thought that he was due for a rise in wages. The old Jew said: "Well, let us see. There are $365\frac{1}{4}$ days in a year, say 366. You work eight hours per day, that is one-third of a day, so if you work *every* day you actually work 122 days per year. Now you do not work on Sundays and you do not work on Saturdays because that is the Jewish Sunday, so that knocks off 104 days leaving eighteen, now you have a fortnight's holiday, fourteen days, and there are four bank holidays a year, so you work nothing, so why should I pay you at all?"

Many inventors after experimenting successfully with models have been surprised and bitterly disappointed to find that the full scale venture was a complete failure. It is entirely fallacious to suppose that because a model of a machine works successfully, therefore the full size machine will be equally successful and will behave in precisely the same way. The reason is that in stepping from one scale to another scale the relationship of the various forces brought into play gets completely altered. In nearly all machines and contrivances forces play an important part. If the relationship of the various forces brought into play becomes upset the action of the machine or contrivance may be entirely altered.

A little analysis will make this clear. Let "l" be a characteristic

dimension of the model and " L " be the corresponding dimension for the full size machine. Suppose, for the sake of argument, that the scale of the model was 1/10th, that is $\frac{L}{l} = 10$. Now there might be three types of forces :

(1) Forces depending on the first power of the dimensions, e.g., leverages.
(2) Resistance forces depending on the surface area, i.e., on the square of the dimensions.
(3) Inertia forces depending on the weight of the body, i.e., on the cube of the dimensions.

In moving from the model to the full size machine :

Forces under (1) become 10 times as great.
,, ,, (2) ,, 100 ,, ,,
,, ,, (3) ,, 1,000 ,, ,,

Obviously the balance between the forces on which the successful working of the machine may depend has been completely upset.

This question of models is one about which the greatest care should be exercised. There are innumerable pitfalls for the unwary. A model which is a true model for one particular thing is not necessarily a true model for another. A very simple example is found in the resistance of ships. The resistance of a ship is roughly proportional to the area and the square of the speed. Using large letters for the ship and small ones for the model we have :

$$R \propto L^2 V^2$$
$$r \propto l^2 v^2$$
$$\frac{R}{r} = \frac{L^2}{l^2} \frac{V^2}{v^2}$$

Now for this to be a true model the ratio of the resistances should be the same as the scale ratio and this will only be so if $\frac{V}{v} = \sqrt{\frac{l}{L}}$

Thus the speed of the model should neither be the same as that of the ship nor in simple proportion to the scale to get the correct relationship between the resistances. Actually, the model speed should be greater than the ship speed to give the resistances in the same proportion as the scale.

This danger of arguing from models is shown very clearly also in the simple structural example of a beam. Consider the stress produced in a beam due to deflection under its own weight. In the usual nomenclature : $\frac{p}{y} = \frac{m}{i}$

If we use capital letters for the full size beam :

$$\frac{P}{Y} = \frac{M}{I}$$

so that we have:

$$p = \frac{my}{i} \quad \text{and} \quad P = \frac{MY}{I}$$

If "w" and "W" are the weights of the two beams:

$$p \propto \frac{w.l.y.}{i} \quad \text{and} \quad P \propto \frac{W.L.Y.}{I}$$

Now "y" and "Y" are of the dimensions of length and "i" and "I" of (length)^4, hence we have:

$$p \propto \frac{w.l.l.}{l^4} \quad \text{and} \quad P \propto \frac{W.L.L.}{L^4}$$

$$\text{or:} \quad p \propto \frac{w}{l^3} \quad \text{and} \quad P \propto \frac{W}{L^3}$$

$$\text{i.e.:} \quad p \propto \frac{l^3}{l} = \propto l.$$

Now the conditions will be that the stress in the model and full scale structure should be the same, since in general the model and structure will be made of the same material, and since in general also the model will be used to investigate a possible breakdown. For equal stresses the weights should be in proportion to the scale^2.

$$\text{If } p = P \text{ then } \frac{w}{l^3} = \frac{W}{L^3}$$

$$\text{or} \quad \frac{w}{W} = \frac{l^2}{L^2}$$

Now the weights of the structure and model are proportional to (length)^3 hence it is obvious that these weights must be corrected if the stresses are to be the same. The weights must be in proportion to the square of the scale. An example will make this clear. Suppose the model was $\frac{1}{4}$ scale, that is $\frac{l}{L} = \frac{1}{4}$. And that the weight of the unadjusted model was 10 lbs., then the beam would weigh 640 lbs. and the ratio of weights would be:

$$\frac{\text{Model weight}}{\text{Beam weight}} = \frac{10}{640} = 1$$

But for equal stresses the ratio should be $\frac{1}{16}$, hence 30 lbs. must be added to the model beam in addition to its own weight. If this correction were not applied the stresses in the structure would be much greater than those in the beam. Taking the same figures:

$$p \propto \frac{w}{l^2} \propto \frac{10}{1} \propto 10$$

$$P \propto \frac{W}{L^2} \propto \frac{640}{16} \propto 40$$

Hence it is obvious that if the stress in the model were the safe limiting stress, the structure would collapse.

This shows very clearly the extreme care which must be used in deducing results from model experiments and explains why many an inventor has been misled by the successful working of a model.

It can be shown that if Δ and δ are the two deflections :

$$\frac{\Delta}{\delta} = \frac{W.l.}{w.L.}$$

If $\frac{W}{w}$ is made equal to $\frac{L^2}{l^2}$ as is required for equal stresses, then :

$$\frac{\Delta}{\delta} = \frac{L}{l}$$

that is the deflections will be similar. If, on the other hand, the weights are uncorrected :

$\frac{W}{w}$ is equal to $\left(\frac{L}{l}\right)^3$ and

$$\frac{\Delta}{\delta} = \left(\frac{L}{l}\right)^2$$

which means that the deflection of the structure is greater than that of the model in the square of the scale. Hence, although a member in the model might be adequately stiff, the corresponding member in the full scale structure might be much too flexible.

There are two fallacies fairly widely spread both arising from confused ideas on density. One is that a steel ship sunk in very deep water will never reach the bottom but will remain floating at some intermediate level. The idea, of course, is quite erroneous and arises from confusing pressure with density. At great depths the intensity of pressure due to the head of water is tremendous but as water is only slightly compressible the density is only slightly increased. Thus at a depth of two miles the pressure will be about 4,600 lb. per square inch, but the density will only have increased from 1 to 1.01, hence the ship will sink right to the bottom.

The other fallacy deals with the lift of an airship. To avoid the risk of fire it would be desirable to inflate an airship with helium.

As helium is twice as heavy as hydrogen many people imagine that the airship would have only half the lift. This is quite wrong, the loss of lift is very much less. The density of air taking hydrogen as 1 is 14.4 and helium is 2. The available lift is proportional to the difference in the densities, with hydrogen the lift would be proportional to 13.4, with helium to 12.4. The difference is only about 7½ per cent.

Meteorology is a field wherein one may find one or two fallacies. One often hears it stated that the seasons are changing, that the winters are becoming milder and the summers cooler, that a generation ago winters were more severe with more snow and frost than at the present time. I am afraid this only shows how little we can trust our memories. Sir Richard Gregory in 1915 said that when meteorological records are examined they show that temperature, rainfall, snow, and frost, are much the same as a generation ago.

In an address to the British Association in 1908, Sir John Moore stated that no appreciable change had taken place in the climate of the British Isles during the last six centuries. From the published weather records of various towns in Europe I have prepared some graphs of temperature and rainfall for a typical winter and summer month, December and June. These graphs show clearly that, while there are considerable fluctuations, there is no steady change in any direction.

The moon is often said to influence our weather, particularly at the period of new moon. I have heard it stated frequently that if the new moon is on its back weather will be fine, if upright wet. Richard Inwards, president of the Royal Meteorological Society in 1895, said that careful observations show the idea of the moon influencing the weather to be a fallacy.

Another common belief is that exceptional visibility is a sign of rain. W. H. Pick, of the Meteorological Office, made observations on this at Cranwell in Lincolnshire, in 1920 and 1921. Observations were taken on 518 days. There was no evidence that a day of good visibility is more likely to be followed by rain than a day of low visibility. If anything it is rather the reverse. I think it is now generally accepted to be a fallacy that a large crop of berries such as hips and haws means a severe winter. It is much more an indication of the kind of spring and summer which have gone than of the winter to come.

I am not sure if my next fallacy is particularly widespread but I have come across it occasionally. It is that the normal human eye is a perfect optical instrument. Helmholtz, the German scientist, comment was " that if an optician had sold him an instrument so carelessly made he would have returned it." Bidwell F. R. S. admits that it is a marvellous structure but full of imperfections. The aqueous surface of the lens formed by the aqueous humour

and the cornea is not a surface of revolution, the curvature is greater in the vertical than in the horizontal direction with impairment of the sharpness of the image. The crystalline lens is formed of separate portions imperfectly joined together. Striae occur at the junctions giving scattering of light. The correction for chromatic and spherical aberration is imperfect. So much for the eye.

One often hears laments by people more sentimental than scientific that this or that particular art has been lost. There are very few arts which have been really lost. In most cases they have dropped out of use. I do not think there is the slightest doubt but that we could practice again to-day, if we wished, any of the arts which have been practised in ancient times. Our knowledge of the chemical and physical properties of materials is so incomparably greater that we could equal if not surpass anything that has been done in the past. A particularly favourite field for the sentimentalist is that of colour. According to some there are, in mediæval pictures and stained glass, colours which cannot be reproduced to-day. Frankly I do not believe it. We know far more to-day about paints and pigments than any mediæval artist ever did and in so far as the particular colours in question are dependent on choice of materials they could easily be reproduced. It is possible, of course, that some of the colours are due to slow chemical changes brought about by the passage of time, but the original artist cannot be given any credit for that. He painted his pictures or stained his glass for his day and generation, not for the people who were to live in the twentieth century. It is quite possible, too, that even this effect due to ageing could be reproduced artificially in a much shorter time, in fact it may be already in operation turning out genuine old masters. One must remember, too, that their scarcity gives old works of art an entirely fictitious value, and when the price of a picture is reckoned in tens of thousands of pounds it is a fallacy to imagine that even average man, far less the art enthusiast, can appraise it with a coldly critical eye.

An excellent example of this theory of lost arts is the fallacy that the secret of hardening copper has been lost. It is often stated in print that the ancients, particularly the Egyptians, knew of an art to harden copper and that this art has now been lost. This is a complete fallacy. Copper tools could be produced to-day quite equal, if not superior to any tools ever used by the ancients. Faraday produced an alloy of copper which took an edge so keen that quite a serviceable razor could be made from it. The reason why we do not use copper tools to-day is that steel can be made so much harder and so much cheaper that it would be ridiculous to use copper in its place. Hence copper comes to be used only for those jobs where its natural properties of softness and ductility render it particularly suitable and thus the idea gets abroad that because its use is

restricted in this manner the art of hardening it has been lost. The very best of the tools used by the ancients would make a poor show if applied to modern work and one can imagine the surprise they would have experienced had they ever been able to handle some of our modern tools with their amazing hardness, strength, and endurance.

While on the subject of copper I might mention another common fallacy connected with this metal, and that is that a copper-zinc ring worn on the finger is a cure for rheumatism. The reason usually given is that it causes a flow of electricity in the body. This is sheer nonsense. The wearing of such a ring would have absolutely no effect at all. This fallacy has no doubt arisen from the fact that copper and zinc are the two metals used in the construction of a Daniell cell, but in that case the metals are immersed in a solution of dilute sulphuric acid and copper sulphate, and if joined externally a current does flow in the circuit. But if they are welded together to form a ring and worn on the hand, there can be no possible effect whatever.

Water divining, by the aid of a divining rod, is an art about which there is still a great deal of controversy, but scientists generally have come to the conclusion that it is a fallacy. The rod is regarded now as a dramatic accessory and not as a necessity. If the diviner is successful in finding water it is due to his knowledge of geology and local topography rather than to any sixth or seventh sense which makes the rod twitch in his fingers when standing over water. One argument in favour of the whole thing being a fallacy is that there is not one single recorded case, in the four centuries that the divining rod has been employed, of a blind diviner. But much stronger evidence can be drawn from specially conducted tests carried out by Professor J. Wertheimer, of Bristol University, Professor C. V. Boys, and Sir Ray Lankester. Professor J. Wertheimer carried out experiments at Bristol with a Mr. Pavey, who claimed to be able to tell by means of his divining rod whether the water were flowing in an iron main underneath the ground. The water was to be turned on and off and Mr. Pavey was prepared, with the aid of his divining rod, to say when each operation was carried out. Ten trials were made and he was wrong every time. Three diviners were each allowed two tries at locating a deep well in the kitchen of Brinslington Hall. Not one of the six attempts was correct.

Sir Ray Lankester conducted a diviner over the grounds of a castle, and his rod indicated the presence of water at eleven different places. He was then taken back to the castle, blindfolded, and led out again over the same route as before but in the opposite direction. Again the rod indicated the presence of water eleven times, but not one of the first eleven agreed with any of the second eleven.

Finally, he was led to a spot vertically over a large conduit through which water was passing, and his rod indicated nothing at all. In another set of experiments made with seven diviners at Guildford, all of them failed to record the presence of a spring with a flow of 50,000 gallons per hour. The general result of these tests is to discredit entirely the fantastic claims of water diviners. There seems little doubt but that the hazel twig is much more ornamental than useful, and that geological knowledge and knowledge of the surface indications of hidden water are the things that really matter.

Before passing on to paradoxes there are four little household fallacies I might mention. Perhaps they are no longer fallacies in these enlightened days. If so, I hope you will forgive me. The first is that a thaw bursts water pipes. It is the frost, of course, which bursts water pipes, the thaw merely gives indication of damage already done. It is interesting to note that if it were a feasible proposition to make all our pipes oval instead of round we would have no burst pipes.

The second is that the sun shining on a fire puts it out. This, of course, is utter rubbish, the sun cannot possibly affect a fire in that way. All that happens is that in the bright light of the sun the fire appears dull. The light given out by a fire is never at any time dazzling, and hence brilliant sunlight can easily make it look dead and lifeless. It would be just as reasonable, or rather unreasonable, to say that the sun has a bad effect on the lighting battery of a motor car because the most dazzling pair of headlights by night look quite insignificant by day. It is all a question of relative brightness. If, when the fire looked quite dead with the sun shining, close fitting shutters could be applied to the windows, the fire would then appear as bright as ever. Professor le Coute in the United States actually tried the experiment of measuring the rate of combustion in a sunlight and in a darkened room. As was to be expected there was no difference in the two rates.

Three years ago I came across a fallacy quite new to me, even more absurd than usual. I would not mention it except that it seems more widespread than I thought. It is that a fire will draw better if a poker is placed standing vertical up against the ribs in the middle. I cannot imagine what can be the origin of such an absurdity.

The last one is that a gas fire dries the air in a room. The origin of the belief is quite understandable, but the belief is, nevertheless, quite wrong. A gas fire cannot " dry " air any more than a coal fire can, that is, dry it in the sense of removing moisture from it. It can only heat it, and the heat from a gas fire is just the same as any other form of heat. It is not a special kind of *dry* heat as some people imagine it to be. But most of the early gas fires had an inadequate size of outlet flue. This would restrict the circulation of air through the room and would give a stuffy feeling to the air.

Lack of sufficient circulation of air and not any peculiar nature of the heat is the real explanation. The cure is not a dish of water in front of the fire but a larger outlet flue.

This completes the few fallacies I wanted to put before you. These are the things currently supposed to be true which are not. I am now going to mention a few things which apparently ought not to be true but which are.

The first paradox I am going to mention is one connected with rates of increase. A great deal of confused thinking is current on this subject. I propose illustrating it by an example on salaries. Suppose that one was offered a salary with alternative methods of increment, say £20 per annum or £5 every six months. Which is the better? It seems absurd, but £5 every six months is the better of the two. This is easily seen by taking the earnings over a period of, say, five years. Imagine the salary to be £200.

Year :	Total Income. £20 per annum.	£5 every six months.
		£100
1	£200	105——205
		110
2	220	115——225
		120
3	240	125——245
		130
4	260	135——265
		140
5	280	145——285
	£1,200	£1,225

The reason is that £5 every six months is at the rate of £10 per annum and £10 per annum twice a year is better than £20 once a year.

Our senses, particularly our eyes, are playing us paradoxical tricks every day of our lives. One often hears in argument the indignant question "do you think I can't believe the evidence of my own senses?" and the answer is emphatically that you can't. We are quite unable to apprehend things accurately by our senses and the frequency and extent of our self-deception is far greater than we usually imagine simply because it is not brought home to us by comparison with reliable standards. Most of you are familiar, I am sure, with the various standard examples on this subject, but there is one very interesting example which is not so well known and which has an extremely important application in industry.

And that is that the apparent pace of a moving object depends on the intensity of the illumination falling on it. The greater the intensity, that is, the more light there is by which to see it, the slower does it appear to be moving. This is important in factories where it is found that adequate illumination actually increases output, the reason being that moving things appear to be going more slowly and therefore the worker makes decisions more rapidly and can actually work faster.

An interesting mechanical paradox is the Roberval "static enigma" first invented by Jean Personne de Roberval in the latter half of the seventeenth century. The paradox is that with a special system of levers forming an accurate parallelogram, the weights can be attached to any part of the two vertical members and the machine remains in balance. This prineiple is used in quite a number of weighing machines to-day, the important point being that the weight and stuff being weighed can be put at any point of the scale pan without affecting the accuracy of weighing.

Probably no scientific field offers as many paradoxes as the particular section which treats of the motion of fluids. Many queer happenings are to be found here. For example, it seems surprising that the resistance of a submarine should be less when submerged than when on the surface, but this is actually the case. The reason is that the resistance to motion on the surface is made up of two parts, one due to skin friction and one due to the waves and eddies created. Every wave and eddy set up represents a resistance since energy has had to be supplied to set the wave or eddy in motion. Now the resistance due to waves and eddies is greater than the resistance due to skin friction. When the submarine is submerged there is no free surface, consequently no waves are formed. Also the eddies formed behind a totally submerged body are not as numerous as behind a body moving on the surface. The main resistance is then due to skin friction and this, when the submarine is submerged, is less than the skin friction and wave resistance and eddies when it is on the surface. The relative value is about one half. À propos of this it may be of interest to note that the resistance of a ship in deep water is less than in shallow water because waves and eddies are not so easily created. On this account the favourite place for running ship trials in this country is on the measured mile on the Clyde. Here the water is deeper than elsewhere and the resistance being less the speed obtained for a given engine power will be greater.

Another interesting fact regarding the resistance offered by fluids to the motion of bodies through them is that the suction effect at the tail is more important than the head on resistance at the nose. This is due to the fact that after the maximum section of the body is passed the stream lines tend to break away from it

with formation of eddies. This causes the pressure over the tail to be less than the hydrostatic pressure and so adds to the resistance. For this reason special care must be exercised in designing the shape of all bodies which have to travel at high speed. The maximum section is never put at the middle but forward of it so that the tail lines can be made finer than the head lines. Fast swimming fishes have shapes of this nature and a photograph of any of the specially designed racing cars will show how carefully the tail of the car is tapered off.

A storm of wind sometimes produces some astonishing effects in the way of destruction to roofs and buildings. Contrary to the general belief, a roof is not always blown off, sometimes it is sucked off. In some cases the suction effect can be so strong as to lift the roof up against the wind. The effects are due to the nature of the circulation of air set up around the roof.

This same effect has been put to practical use in the Flettner rotor ship. In this ship two large rotating towers take the place of sails. The towers are driven by electric motors and the result is that in a wind a side force is produced on the towers. The angle which this force makes with the wind depends on the relative speed of the wind and the tower. With this arrangement it is possible to sail closer to the wind than with sails and it is about eight times more effective in converting the energy of the wind for propulsion purposes. This side force which acts on any rotating body in a wind is well exemplified in the curved path followed by a tennis or golf ball when hit with cut on it.

The final paradox with which I am going to deal is one connected with explosions. When an explosion takes place in a street and windows are shattered, the majority of the windows are not blown in as one might expect but are blown out. The windows very close at hand to the explosion may be blown inwards but in the majority of cases careful inspection will show that the glass has come outwards. The reason is as follows. When an explosion takes place on the ground the sudden formation of gases by the chemical action causes a pressure wave to set off in all directions. Windows very near the origin of this wave may be blown in but the majority a little further away will not be splintered. But, following on this pressure wave, comes a rarefaction or suction wave in which the pressure is less than atmospheric. This wave lasts longer than the pressure wave and is consequently more destructive. The result is that the windows get blown out under the action of the atmospheric pressure inside the house.

Some excellent examples of this paradox were furnished by the Zeppelin raids on London during the war. I will quote three examples. On the 8th September, 1915, a bomb was dropped at Golders Green. There was hardly an exception to the rule that

the windows were blown out. The phenomenon was particularly well shown on this occasion as many of the houses in the vicinity had leaded windows and the lead-work could be clearly seen bulging outwards. On the 13th October, 1915, bombs were dropped in the neighbourhood of Aldwych and Lincoln's Inn. A large hoarding cutting off a building site from the street was flattened towards the spot where the bomb had exploded. The third example is particularly interesting. A bomb fell in a street and, as usual, most of the windows were blown out. A photographer's show-case, 20 yards nearer the bomb than any of the windows, was unbroken. It was a very shallow case and apparently there wasn't enough air behind the case front to expand and shatter it. A fence which was between the case and the bomb was flattened towards the bomb hole.

The fact that a suction wave follows an explosion wave can be easily illustrated by firing a blank cartridge along a paper tube when the tube will be found to collapse inwards.

Discussion.

MR. E. W. FIELD (Section President) thanked Dr. Anderson for his lecture, and observed that he would certainly remember that weather curve when he was next on holiday. Dr. Anderson had also given them two good points to take home and discuss with their ladies during Christmas—the sun and the fire, and the gas fire and water. An interesting point on which he had not touched when speaking of the golf ball was, what happened when one sliced? Dr. Anderson had proved to his own satisfaction, at least, that a submarine encountered less resistance when under the water than it did on the surface. If that was so, why was a submarine faster on the surface than when submerged? Was it due to the power employed?

DR. ANDERSON said that if he knew the cause of slicing, he would have cured his own long ago. With regard to the speed of the submarine, it was a question of the different method of propulsion. On the surface the propelling unit would be oil engines or turbines, and submerged it would have to rely on the batteries.

MR. T. JACOBS referred to the device for perpetual motion. Could Dr. Anderson tell him how long one of those machines would run before stopping?

DR. ANDERSON replied that this would depend on the amount of initial push given to it and the amount of friction present.

MR. JACOBS said that a friend of his had built a similar machine. He started it by hand, and at the end of forty-eight hours movement, stopped it by hand. It became, of course, slower and slower, but did not stop in that time.

DR. ANDERSON admitted that there were many recorded cases in which a machine went on for weeks, but there was usually a clock-work mechanism inside.—(Laughter). He did not, of course, cast any aspersion on the machine made by Mr. Jacob's friend, but definitely it would not go on for ever.

MR. J. A. HANNAY referred to the periods of exceptionally good visibility, and rain or bad weather following. In his experience, bad weather always did follow extremely good visibility.

With reference to the illustration showing how to get an extra square in, Mr. Hannay pointed out that this had an application for the production engineer. He had himself found that a considerable saving could be effected by making packing cases, buildings, etc. as nearly cubes as possible, and he thought it was probably for this reason that the Chinese set out all their exports in square packing cases.

DR. ANDERSON said it was undoubtedly true that, while a lot of these things were amusing, they had practical applications. On the subject of exceptional visibility followed by rain, he would point out that in making this statement Mr. Hannay was relying on his memory, and had not made serious observations. Now memories were very fallible indeed, and those figures given were obtained from careful observation by the Meteorological Office. He would suggest that Mr. Hannay should, over the next two years, take careful note of the occasions on which exceptional visibility was followed by a fine day, and by a wet day, and tot them up!

MR. FREEMAN had been interested in Dr. Anderson's local resistance experiments, which clearly showed that at a depth there was far less resistance than was encountered at water level. He believed that the procedure during the war, when an enemy submarine was located, was to send fast destroyers in circles round the submerged submarine in order to raise it. Would Dr. Anderson tell them if the principle was the same?

DR. ANDERSON regretted he could not answer Mr. Freeman's query about destroyers and submarines, but was inclined to say "No." He rather imagined that in the presence of an enemy submarine it was usual tactics to circle. He had been in the Navy and had some experience of that. The circling was not with the object of creating suction.

A VISITOR spoke with reference to the rotor ship mentioned by the lecturer. He believed he was correct in saying that it had been a signal failure, and she now had engines in her and was employed in transport. He would also like to have a little more information about how those roofs worked. Some of those present would remember the gale which struck Sparkhill, and certainly a number of houses were then blown outwards, but he could not quite grasp yet how the suction worked on those models.

DR. ANDERSON, referring to the destructive power of the suction wave said it was due to the expansion of the air inside the houses. There was a very low pressure zone outside, and the air inside expanded. The storm in Birmingham had been in the form of a tornado, which is characterised by a zone of low pressure. The air inside the houses expanded, and, of course, just pushed the roof off. Generally speaking, houses were built so that they were weaker so far as the roof was concerned, in withstanding inside pressure rather than outside pressure. Hence the roof would come off and the walls go out. There had been a case during the war which illustrated this admirably. A bomb fell into a street, and the windows for a long way were blown out, but a photographer's glass case was undamaged, for the reason that the volume of air behind the glass was not sufficient to expand and burst it

MR. GARDNER referred to air resistance in connection with the

serrations on golf balls, and asked the lecturer to say something on this point. Also, he had heard it stated that if a ship were cut in two it would be as easy to tow the equilateral triangle through the water as it would be to tow it point first.

DR. ANDERSON replied that, with regard to the serrations on the golf ball, he did not think these really mattered at all. It was purely a question of sales propaganda. When the dimpled ball was introduced, the manufacturers said that when the ball was put onto the ground, there was suction as a result of the dimple, and one could hit the ball much more crisply, but this was not true. It was merely a talking point. As a matter of fact, he had experimented with a coarse sand paper wrapping on the rotating cylinder apparatus thinking this would give a much bigger circulation of air than a perfectly smooth surface, but he found that the sideways force was unaltered. He did not think there was anything in the serrations at all. With regard to towing the ship, it would not surprise him if there were more resistance when it was towed point end first. In the case of bodies passing through fluids, the suction at the tail end was much more important than the head-on resistance at the nose. If a triangle were towed through fluid, apex first, there would be eddies at the back of it, and a very marked suction effect. If it were towed the other way, base first, the resistance might actually be less. One saw this, of course, in the design of any body for high speeds through fluid. The maximum section of an airship was well forward.

MR. E. W. FIELD asked why, if it was claimed that an eliptica pipe was less likely to crack than a round pipe, was it not done commercially ?

DR. ANDERSON replied that it was simply cost, and difficulty of manufacture and jointing.

MR. FIELD asked if it would not be better to make eliptical pipes and avoid the necessity of packing to protect the pipe from the frost ?

DR. ANDERSON replied that it was a matter of standardisation. The eliptical pipe would be expensive because we could not have eliptical nuts.

MR. FIELD inquired if nuts were always used for such pipes ?

DR. ANDERSON said he was thinking of modern copper installations. Perhaps there were some plumbers present who could tell him whether eliptical joints could be as easily wiped as round joints.

MR. I. H. WRIGHT suggested that an oval pipe would, in practice, be oval the first winter, but that its lack of elasticity and volumetric change in the water would make it round for the next few winters.

DR. ANDERSON agreed that it would actually become rounder

each time it froze, though, of course, in these mild winters, it probably would not freeze at all.—(Laughter).

MR. BIRMAN thought that the lecturer ought to have stated, when speaking of perpetual motion, that he was speaking of terrestrial matters and not in an astronomical sense.

DR. ANDERSON agreed he ought to have qualified his remarks; so far as he knew, the astronomical motion was perpetual.

MR. D. A. TILT (Chairman, Graduate Section), asked the lecturer to explain why one saw, in films, the wheels of motor cars going in the reverse direction?

DR. ANDERSON thought the explanation might be that the film consisted of a series of entirely separate pictures, and that when the first picture was taken, the motor car wheel spokes might be at one position, and it might make a dozen revolutions before the next picture was taken, and the spoke might then be a little in the rear of its previous position. This method was used in the devices now on the market for examining moving mechanisms. By this means, one could actually see something which was moving at 3,000 revolutions per minute, appear to creep round.

MR. R. H. YOUNGASH in proposing a vote of thanks to the lecturer, raised some points on which the lecturer had not touched directly during the evening.

His mention of leverages reminded him that thirty or thirty-five years ago a company had been formed in Birmingham, with considerable capital, for the purpose of making bicycle chains, which was based entirely on that fallacy. Another point he would like to raise, he did not know whether to call it a scientific fallacy or not, concerned the flat earth theory. It was an experiment, about which some members had probably read, made many years ago, in which some people took a stretch of canal and put a square of sail at one end and an observer at the other, and claimed that they were able to see that sail many miles further than the curve of the earth should have allowed. Another, perhaps, unscientific fallacy was that when crows built their nests high up in the trees, the summer would be fine, and if they built low, it would be wet. It was curious, however, to note that during last spring they did build high, and that an exceptionally good summer followed!

When oval water pipes had first been mentioned he had felt inclined to go home and knock every lead pipe oval, but the discussion since had brought out the fact that the oval pipe would have a nasty trick of becoming round again when frost came along, and he would abandon the idea. He was reminded of an instance in which a well-known motor engineer, years ago, had put into his cylinder blocks a copper disc in order that, if the cylinder froze, this copper disc would push out and avoid bursting due to freezing.

DR. ANDERSON: How did he put it in?

MR. YOUNGASH said that he just pushed it in. As a matter of fact, there were several discs put at convenient spots in the outer shell of the cylinder.

Mr. Youngash concluded by proposing that a hearty vote of thanks be accorded to Dr. Anderson for his interesting, able, and instructive lecture.

DR. ANDERSON thanked the audience for their cordial reception of his lecture, and dealt briefly with some points raised by Mr. Youngash. He had mentioned the experiment on the straight canal. Really, one could not comment on experiments of that kind unless one had all the data, such as, how long a stretch of canal was used. He would rather imagine that the snag lay in their calculations, and he doubted whether one could get a stretch of canal sufficiently long to get any measurable curve at all. With regard to the crows building nests high in the trees, he would be very chary indeed of saying that was a fallacy. Observation had shown that animals had some sense, which we had not, which enabled them to foretell weather conditions. Our knowledge of mysterious factors such as the cosmic rays, and the probability that our weather was related to thickness and thinness of the ozone layer of the upper atmosphere, made it within the bounds of possibility that the animal body might be sensitive to some things like that.

PSYCHOLOGICAL AIDS TO INCREASED PRODUCTION.

Paper presented to the Institution, Western Section, by Dr. G. H. Miles, National Institute of Industrial Psychology.

YOUR President, Mr. Whitehead, has told you that he is rather ignorant of this subject; but this afternoon he has taken me round his works and showed me what has been done there. Even if he disavows any knowledge of psychology, he has done quite a lot in his own works which is in accordance with the laws of psychology. In fact, everyone of you must at some time or another have applied from his own practical experience, commonsense, and observation many of the things which the psychologist is trying to arrange in an ordered and practical manner. To-night I shall try to give you some idea of the ways in which a study of the human side of production can increase production and improve working conditions.

A production engineer has at his disposal very efficient and elaborate machinery, and intricate methods, and these are so complicated that they demand nearly his whole attention. They are so interesting that they tend to draw to themselves attention that might better be employed in other ways. When going round your president's works this afternoon, I found myself so attracted to the mechanical side by the ingenious methods adopted, that I almost failed to keep an eye on the human side: with all this ingenious and interesting machinery there is a danger that too much interest will be focused on the purely material side of the production engineer's problem, and that the human side will be overlooked.

A production engineer has two main objects—to increase production, and to reduce costs. Costs of production are frequently reduced enormously by machinery—a fact that in itself supports the tendency to focus attention on the mechanical side. In the old days, when the introduction of machinery had reduced labour costs as far as it could, further reductions were sought by cutting piece-rates or by shortening the times allowed. This sort of thing in itself is harmful, and we are still suffering from the effects of unjust reductions in order to reduce production costs. The National Institute of Industrial Psychology has proved again and again that it is possible both to increase production and at the same time to improve

February 9th, 1934.

working conditions ; to give the employer the benefits of increased production, lower costs, less waste, better morale and a more contented staff ; and to give the worker the benefit of higher earnings, better working conditions, and the elimination of those hundred-and-one petty annoyances and irritations which so often make their work a purgatory.

When material such as steel, cotton, paper, leather, or any other raw material is brought into a works, it is generally very carefully inspected to see it is up to the standard. In many works, indeed, special departments exist purely for this examination. Elaborate arrangements are made for the examination of raw material, but little provision is made for the examination of the *human* material that comes into the works.

Now one of the very best ways possible for reducing production costs is to make sure that every one of your employees is " the right man in the right job "—to select your workers, in fact, with the same care and precision which you use for your raw materials. Just as the chemist, the physicist, the engineer gives you tests for your concrete materials, so the psychologist can give you tests for your human " material."

In an engineering works in Scotland the Institute prepared a series of simple tests to be used with boys who were being considered for engineering apprenticeships. After three or four years a director told me that by means of these tests they could find out more about a boy's suitability in an hour than in three months' work in the shops ; and he said that the tests had enormously reduced the proportion of " handless " boys.

In practically every branch of industry, the Institute has proved, by actual results, the value of tests in selecting new workers. We devised a set of them for a spinning works in Ireland. People who applied at the gates were tested, and the results were recorded on cards with the name and address of the applicant. When new workers were required, they sent a boy on a bicycle to the suitable workers to tell them that they would be given work if they applied at the mill.

The first result was that the amount of time spent in training incoming labour was reduced. Then they found that they engaged better operatives and, moreover, operatives who were interested in their work. I went to the mill about three years after the tests had been introduced, and on going through one department I found no foreman in charge ; but the girls were going on happily with their work. I found later that the foreman was attending a foreman's meeting, and I asked him if he could have left the room like that three years before. He replied that if he had left the room for a few minutes in the old days " there would have been

hell's delight" ; but now he had girls who would work without constant supervision and who were interested in their work.

This raises a point which I should like to emphasise. If you have a man who is master of his job, that mastery provides one of the greatest incentives to good work you could possibly have. And the use of selection tests gives you a much better chance of obtaining such really suitable workers than the somewhat haphazard, hit-or-miss methods which are so often used.

Is it possible to tell in the course of an ordinary engagement interview whether a man is really suited for work, say, on an automatic machine, or for the complicated type of job which is common in chemical works? Is it possible, by mere interviewing and questioning, competently to sum up a man's talents and personality? General experience will support my statement that it is not. The widely different qualities which are required for equally different types of work can be measured only by properly constructed tests.

Assuming that a firm has introduced the best methods of selection, in what way does that assist production? In what ways is it better to make sure from the start that only suitable employees are engaged, instead of just trying out those who appear to be all right, and then weeding out the "duds"?

Well, if a firm has a number of workers who turn out to be inefficient and have to be discharged after a month or two, those workers represent a definite increase in overheads. They have been doing less work than suitable men would have done. They have turned out poor work, they have consequently spoiled material; and there is a further intangible overhead which the incompetent worker abstracts from the firm, due to the added supervision he requires and to the fact that the incompetent worker is certainly more trouble all round than the competent worker. This is an added expense that never comes on the cost sheet; but if you compared the value to a firm of an average worker throughout the whole of his working life with the value of a first-class worker over the same period, you would not take long to conclude that it pays to spend a few hours in selecting the right type of worker.

Obtaining the right type of worker is the first step. He has then to be trained; and in this country and in most countries I contend that the training of workers is altogether inadequate. The usual plan adopted is to put the beginners alongside the practiced workers to pick the job up from them. Some factories, it is true, are more systematic and have a training school; but very frequently the head of the training school is a person who is known to be a very good worker.

Possibly the worst type of teacher you can have is the man who knows his job "from A to Z." Very often a person who is

thoroughly expert at his job does not realise a beginner's difficulties, and he interprets lack of progress as lack of intelligence or sometimes as pure cussedness. The highly skilled man is apt to have very little patience with the learner. Further, his skill has often become so much a part of his being that he finds it difficult to explain the key points of the process. In almost all jobs there are these key points, and only when he has grasped these can a beginner make real and rapid progress. Wheeling a wheelbarrow, for instance, over a narrow plank looks easy ; but when you try to do it you are apt to give all your attention to the handles. If you do this you will find the barrow will very soon tip up. The thing to do is to look straight ahead. Or put a penny on the back of your hand, toss it up, and try to catch it. If you do not know the trick it is difficult, as you are apt to watch your hand, and in turning your hand over you knock the penny and do not catch it. The secret lies in keeping your eye on the penny.

In nearly every operation, I repeat, there is some key method ; and in every training school it would pay to have the work analysed from a psychological point of view to find out the points to which attention should be directed. We carried out an interesting experiment in this connection in a large factory in the North of England. We wanted to get two equal groups of workers and test their progress by the two methods of instruction, so we wrote the names down in alphabetical order, and the Institute took the odd numbers (one, three, five, etc.), and the firm took the even numbers (two, four, six, etc.). The Institute trained their group from the pyschological point of view, and the firm trained its group by its own methods. At the end of four weeks the Institute's group was 10 per cent. ahead on production, and after five weeks this figure had mounted to 20 per cent.

Now you can see what that means from a production point of view. Time scored in training is sheer gain. It cuts training costs. It means that a liability—an untrained man—has been converted into an asset—a competent worker—in less time than he otherwise would have been. The firm saves both on direct costs and on indirect overheads.

Now, having got selection and training, the next point is that environmental conditions should be right. You may have the best type of worker, and you may have trained them properly, but if your workshop is badly lighted, for example, you will never get the best work out of them. It is surprising how little attention is given, even now, to lighting in most works, particularly where inspection and work demanding close attention is carried out. The National Institute of Industrial Psychology recently carried out an investigation in a large inspection department, and one of the first things we had to do was to improve the lighting. For

inspection you must have good lighting conditions, not only with regard to the intensity of the light but also with regard to the angle of the light. In another investigation, in a newspaper office in the North of England, the problem was not inspection but assembly. Work in the composing room consisted of the assembling of small pieces of type into words and lines. The foreman in the composing room in this newspaper office told me that he had started off with 30 watt lamps, and that the men complained that these were not sufficient. He fitted 60 watt lamps. They were still not sufficient. He fitted 100 watt lamps and the men still grumbled. So he fitted 120 watt lamps and they still grumbled. So he said "What can you do with a crowd like that?" The trouble was that the room had a low ceiling, and the lights were placed so that a certain amount of direct light entered the worker's eyes. Now light entering the eye in this way causes the pupil to narrow, so that as the intensity of the lamps was increased, so the pupil became smaller, and smaller, and less and less of the light reflected from the work could enter the eye. The result was the apparent paradox that as the light was increased the illumination became less.

We lowered the lights somewhat and enclosed them so that all the light shone on the work and no direct light entered the eyes of the workers. We found then that the 60 watt lamps were perfectly adequate for the job. Therefore we effected two improvements—reduced lighting cost and increased rate of work.

Every job has its own lighting problems, and you can get at them only if you consider the point of view of the men who do the job. You must take the position of the worker and adjust the lighting so that he gets the right type of light—the right quantity, the right quality, the right direction, and sometimes the right colour.

We have been investigating the use of coloured lights. In the examination of screws, we found that a mercury vapour lamp gave the best results. In examining for dirt in coal, we found that with a yellowish light the pieces that had to be rejected stood out much more clearly. A greenish light assisted girls in picking out slightly yellow bristles in a brush making factory. The brushes were of very high quality, and it was essential that the bristles should be white. After a girl had been working for some time, her colour sense was effected and she could not pick out slightly yellow bristles. A greenish background and a slightly greenish light had the effect of accentuating the yellowishness of those bristles which should be rejected, and decreased the amount of eyestrain.

Another environmental factor often overlooked is atmospheric conditions. I was in a bakery not very long ago, and the foreman pointed out a number of his men who were lolling against a pillar and did not seem at all energetic. He blamed schools, cinemas, political propaganda, and all sorts of things for the apparent slack-

ness of these workers ; but I guessed that hot and stagnant air was the true explanation. Measurement of atmospheric conditions confirmed my guess. In that particular bakery they were expecting white men to do work under atmospheric conditions suited only for black men. There was so much moisture in the air, and the temperature was so high, that they had practically a semi-tropical climate. It was absolutely impossible for those men to do good work under those conditions.

By giving attention to such general environmental factors it is possible to improve output by from 10 to 20 per cent.

Most production engineers give very careful attention to the selection of machines in their particular factory. They are not content with buying the first one they see. They get catalogues ; they see the machines in operation ; and not until they are entirely satisfied is the machine installed.

But many machines will produce at the maker's rate only if the operator is not fatigued, but how often does the very design of the machine make fatigue inevitable ? Controls are in awkward positions, causing strained posture, tiring stretches, causing fatigue in the operator which at once militates against the efficiency of the machine. There are some engineers who seem incapable of realising that machines are operated by human being.

There are many other non-mechanical factors which effect the efficiency of a machine. The lighting may be unsuitable, supplies of material may be brought to the machine at a wrong level, and the space allocated for the machined product may be too small or placed in an awkward position. Tools and accessories may not be handy, and so on. For full efficiency it is essential not to regard the machine as complete in itself, but to consider it always in conjunction with the man who will have to operate it.

Nothing like sufficient attention is given to the machine plus the man. I have seen many layouts for new factories in which squares have been marked on the plan to represent the ground area of the machine. Then it is said " That looks all right, we will go on with that layout." Such a layout is planned without regard to some of the essential considerations. The plan should show the machine, plus track and worker, plus a space for the raw material, plus a space for the finished product, and the whole lot should be marked out before any planning is done, so that gangway spaces an working spaces shall be adequtae. In many factories I have seen machines pushed into such positions that it is impossible for any worker to do good work, because he has not sufficient elbow room.

With most machines, there are certain accessories—files, spanners, and wrenches, all sorts of small tools and gadgets—on which the effective operation of the machine largely depends. It is a common experience to find a factory equipped with excellent machinery—

except that these tools and tackle are inadequate. I have seen men working with files not up to standard, hack saws not in the best condition, spanners the worse for wear. Very frequently tools are lost. In a factory in which we worked, a large number of presses were in operation, they were steam heated and pressed soft material in certain shapes. Three or four spanners were required for each. We found that the number of spanners was insufficient, and that men were wasting time in going from one press to another to borrow a spanner and then in going back to return it. That was remedied and spanners were supplied and fastened to each machine on a chain. It is surprising how frequently such small points are overlooked. In another instance, production was considerably lower than the type of machine warranted. This was found to be almost entirely due to the fact that some of the machines were comparatively old, and it took more time to set these machines, more gauging was necessary, and more adjustment than on the new machines. The old machines greatly reduced the average production of the whole group. We advised the firm to scrap the old machines : they did so, and production went up 36 per cent.

Machines and tools should be of the best. It is a great encouragement and incentive to the worker to have first-class machines and equipment.

In up-to-date works the supply and removal of material is very carefully studied, but even in the best I have found instances where a more systematic removal of finished material would be very well repaid. The provision of suitable containers is usually a wise outlay. It has the effect of instilling habits of orderliness and tidiness, and this is an incentive which cannot be overestimated. A further incentive is giving a man " plenty on his plate " to be getting on with ; and a good system of routing and removal, by doing this, usually results in an increase in production.

Another important factor is the effect on a worker of the quantity of work which he has to tackle. We had a very interesting case of this in a jam factory. Their workers were supplied with a stone of currants at a time for picking and sorting. Towards the end of the morning, the girl got tired and bored, so we arranged for her to be supplied with only half a stone of fruit at a time.The result astonished us ; her output doubled. This seems incredible, but we have definite figures. The improvement was due to the fact that the big quantity seemed an endless task. With the smaller quantity, there was some relief in sight, where there would be a change through having the work checked off.

Very often rest pauses have a similar beneficial effect. Just imagine being doomed to carry out regular routine work day after day, week after week, year after year, practically the whole of your life. It would be deadly monotonous anyway ; but if the

work is arranged in comparatively short spells, it would be more tolerable than if the working spells were long. By breaking up the working period, rest pauses reduce fatigue and boredom and the bad effects that result from them. Workers on piece rates, it is true, sometimes oppose pauses, but this opposition can usually be overcome. In one factory, we arranged that a change should be made during the pause from one kind of work to another, and a 10 per cent. increase in output resulted from this change pause. In a large spinning mill, we were able to introduce a rest pause even where production depended on turning off a large quantity in a given time. In spinning, the loss of yarn during a ten minutes' rest pause would be serious. Our method of dealing with that difficulty may be illustrated by a motoring analogy. Most of you know that after you have been driving a car at, say, 45 miles per hour, and then slow down to 30 miles an hour, you think you are going at a crawl. There is an old Brooklands tale about a car that had been going at 100 m.p.h., and when the driver slowed to 20 the mechanic thought they had stopped and got out. In the spinning mill the spinning frames were reduced in speed by 25 per cent. and the girls thought they were going at half speed, and it was possible by that means to send half of them out for a rest pause, while the remaining half looked after the machines. When the first had had their pause the other half went, and the machines ran the whole time at only a 25 per cent. decrease in speed.

I have made no attempt to perform the impossible feat of showing, in one talk, all the contributions which the psychologist can make to industry ; but I think that I have shown that his work is of very real and concrete value. The success of any industrial enterprise depends, ultimately, on the men who are engaged in it. They are at once the most important and the most intricate items. To regard your workers as human machines is as disastrous as it is absurd. The human factor in industry is vitally important, and well deserves special study.

Discussion.

MR. HIGGINS: I think we have heard a very interesting paper but I consider it is too idealistic, and if I may say so, seems rather like pampering the workman. What do we get out of it as engineers? How will psychology assist me in selecting a suitable machinist? The whole thing seems a question of going to extremes, and it would appear that the old efficient type of craftsmen would soon become extinct, and that the new age will be, to a great extent, mechanical robots.

DR. MILES: If by "idealistic" you mean the opposite of "practical," then the Institute's work in factories comes definitely under the "practical" heading. In our investigations we work on the spot on the actual concrete problems of the factory. He does not offer advice from a distant office arm-chair: he is concerned with finding a *practical* solution, of making *practical* improvements. The Institute certainly tries to make work as pleasant as possible for everybody. What reason can there possibly be for making it unnecessarily unpleasant? Pleasant work in good surroundings is usually done more efficiently. It may be said that you "pamper" a worker by giving him a seat instead of making him stand to his work; but by doing so his job is eased, and he will become less fatigued. A fatigued man does less work than a fresh man, and he produces more waste. Providing seats for workers is often desirable from the points of view both of the workers and of the management. The same is true of lighting, ventilation, methods of work, and so on. I agree that the old type of craftsman is an extremely fine type. But we must realise that industrial developments have reduced his scope. With mass production methods specialisation has become essential, and it is becoming more and more important that boys and young workers should be carefully selected for different jobs.

The Institute's method in designing tests for firms is to find out the type of job and the mental or physical points involved, and then to devise tests on these points. Having devised these tests we apply them to men actually in the firm who the firm know are good and thus obtain a standard. By using this standard in the actual tests of applicants for jobs it is possible to get a better type of worker. By this means in several different industries firms have found very definite advantage. The Glasgow firms I mentioned in my lecture and Messrs. Mather and Platt, Manchester, have engineering tests. In another class of trade Messrs. Rowntree, of York, obtained 85 per cent. of accuracy in placing applicants in jobs before they used tests, and by the introduction of tests they

obtained over 95 per cent.—that is to say only five per cent. had to be changed over. I should like any of you who come to London at any time to call in at the Institute, when we should be pleased to show you our tests and let you do some of them. If such tests are used, you are certain to get a better type of worker who is suited to the job he does.

MR. KENWORTHY : I think we are all very satisfied that Dr. Miles has treated his subject very well indeed and given us all something to think about. I was of the opinion that the methods spoken of could not be applied quite the same to skilled labour as they could be to special types of labour. I should think that particular tests are much more applicable to special purpose or quite unskilled labourers who have to be trained for particular jobs, but when one comes to the craftsman who has served an apprenticeship, he should have found his real sphere of usefulness, or should not have survived at his job. From the engineering point of view it seems that these tests should be applied to apprentices where they should give very great assistance. A good many youngsters come into the engineering trade who should never have seen the inside of a workshop, and who never make anything more than a poor operator.

There is one point which Dr. Miles has not mentioned which I think is rather important. Has anything been done in applying these tests at an earlier age, that is, to youths at school ? It seems to me that this is the place where tests should be applied as they would give an idea of the lines on which a youth's training should go. Most youths at a secondary school have no idea of what career would be suitable for them Is it possible to apply tests at that age or is that age too young ? When it comes to the other end of a man's career, is there an age when psychological tests cannot be applied. Are these tests so effective with people at, say, forty years of age or does a man at some time of life get into a groove from which he cannot emerge ? It would be rather interesting to know whether the improvements shown have always been permanent. They have been shown to exist over a period, probably while the Institute's representatives were at the firm, but are they permanent, or do they show any drop off due to perhaps incorrect application after the Institute's representatives have withdrawn ? With regard to lighting, Dr. Miles mentioned that he joined issue with the lighting experts. A number of lighting experts consider that the amount of light necessary can be read by candle meter but also recommend diffused light. I wonder whether Dr. Miles joins issue with that and considers that the application of the light is more important than the amount. In this case lighting becomes rather an involved question except for special purpose operators. With regard to lost spanners and other small equipment I am afraid Dr. Miles' experience in regard to engineering shops is not very

extensive. Unfortunately a spanner has a use in every home, and one of the most difficult things is to prevent such things disappearing.

DR. MILES: Mr. Kenworthy has raised some interesting points. I would rather deprecate setting tests after a man has been in a job for a period. In our experience we find you have got to tackle the incomer. The Institute has prepared tests for engineering apprentices for several firms, and they have proved to be very successful. One of the firms wrote to us that they had definitely proved that the tests give them, in an hour, a measure of the boys' suitability which it would take three to six months to obtain in the works. We have been working in co-operation with the Birmingham Education Committee in connection with tests for engineering apprentices. The aim there is to give advice on careers to all schoolchildren before they leave school, and particular attention is being given to careers in engineering. Vocational guidance is also given to young people at the Institute, after a special examination of their abilities and personal qualities. We examined and advised about 850 cases during 1933. The permanency of the improvements made by the Institute in factories depends largely on the firm. If a firm is content to let things drift, they do. A firm that puts in a new machine gives attention to that machine. If they forgot to oil it or to replace worn parts it would soon go wrong, and the same thing would happen to any system. We always aim at leaving behind systems or methods which members of the management thoroughly understand and can operate. I had a letter only the other day from a firm for whom we did an investigation lasting 5½ years. The letter said that trade was improving and that they were now reaping more and more benefit from the work we did in the 5½ years. Again and again we have had very emphatic statements from firms to the effect that the useful effects of our work persisted long after our investigators left the factory. The point which we emphasise about lighting is that it must be planned for the job. If the lighting is to be right, you must watch the job itself, find the best intensity, the best angle, the best quality and colour. Both intensity and application are important. With regard to tools and equipment, I agree that spanners have a habit of disappearing. In a large repair works, we had a tool rack made for each bench, and the board was blacked at the back of the rack to show the shape of each tool. All tools were kept on the racks in their proper places and it was easy for a man to go round and see if any tools were missing. It is possible to have a simple means of checking tools, and when that is done I think the little trouble taken is well worth while. It is astonishing how much time is lost by men going here and there to fetch and return tools from other machines.

MR. WOOD: I take it that this industrial psychology is a particular

application of general psychology. It can be taken in two ways as far as the Macdougal School and the Behaviourist School of psychology are concerned. The Behaviourist school takes a man as a thing to be worked upon and made into anything you wish. The MacDougal school takes a man as an individual. It seems to me that the method spoken of by the lecturer is of the Behaviourist school and will tend to make the operator into a unit or a part of a machine. I myself, left a job because I found the longer I was on the job, obviously, the better I did it, and the longer I would be kept on it. With regard to spanners I should like to refer to a book published a short time ago, by I think, the T.U.C. or some such body, about six people employed in different kinds of work, including a miner, engineer, and cotton operative, and the engineer said that one of the worst things they had to put up with was the quality of the hand tools and the fact that a man never had a complete set. He said that if a man were given a complete set for his job, his property sense would make him look after them. In his experience it would be better from the point of view of the firm to issue a complete set of tools to each worker. With regard to average intelligence I have read that a certain toffee works found the girls who did their job best were those whose range of thought was limited to cinemas and "best boys." It seems impossible to apply industrial psychology from the point of view of the Behaviourist, and keep the level of intelligence high enough for the operators to be responsible citizens.

Dr. Miles: I agree that the tendency of modern industry does seem to be to limit the aspirations and the possibilities of the human being. A man who is milling day after day, week after week, year after year, does not find in his work scope for all the many possibilities of a human being. The question of compensatory occupations outside the works is bound to become more and more important, so that a man can develop the other sides of his mind. With regard to the question of intelligence, there are certain jobs at which a high level of intelligence is a definite drawback, and an intelligent person is wasted in them from the point of view of the community. This is particularly true of simple monotonous jobs. That is one of the reasons why we emphasise the need for selection. I think the problem we shall have to face in the future will be more a problem of leisure than work. After all, why should we have to work when we can get machines to do it? I am looking forward to the time when hours of labour will be reduced more and more and hours of leisure will be increased and we shall enjoy the world. I cannot see why any person should be doomed to work as they used to in the old days from 6-0 a.m. to 8-0 p.m. every day except Sundays. Why should the whole of a lovely day like we had to-day be spent in work?

MR. MORE: I think it is generally understood that when an operator is on daywork he usually only works at half-speed. Is it possible by giving a man psychological tests to speed him up as much as you can by giving him piece rates?

DR. MILES: This is a very interesting point. In one factory girls were employed on threading needles and doing tapestry work. These girls were day workers and they wasted a certain amount of time threading their needle. This is a fairly easy job, the only skill required being the matching of the colours of the threads, and could be done by learners. So we got youngsters who could do this sorting of colours and needle threading, and to make it an economic proposition added the cost of the needle threading on to the other work. This increased production, but the needle threaders did not thread as many as we hoped. The firm began experiments. The first introduced piece rates, and they found the output went down on the piece rates. They then tried a series of inducements, so many afternoons off for instance. That did not come off. In the end they started a little competition among them as to who could get through the most work in the morning, and got the output up 300 per cent. We find that when piece work is in operation a worker very soon gets a kind of mental standard as to how much he should earn. The piece rate goes up to that standard, but it won't go beyond it. In cases of this sort we have had time and movement studies made and proved that it was possible to get 50 per cent. more output without greater effort, but found it was impossible to get any increase until we got the job split up anew apart from the workers' mental standard, and got an increased mental standard. During the war the increases in output obtained by new workers were almost incredible.

MR. MAWER: I would rather like to hear Dr. Miles' opinions upon a few aspects which he has not already dealt with. I have in mind the effect of supervision on production; on the one hand, if it is of a bullying nature, what is its effect, and on the other, the effect of supervision based on leadership? What effect has discipline on production? Again, we have the effect of the contentment of the worker, justice towards him, and the way an employer deals with grievances. The latter point leads one on to a matter which a previous speaker has touched on, the question of payment by results either by the piece-work or premium bonus system. A worker always has the impression when he is asked to increase output, that if he goes beyond a certain point the rates will be cut. He is often promised that cuts will not be made, but he finds from bitter experience that they invariably are.

DR. MILES: Supervison is one of the points I omitted from my lecture, but it is a very important one. I don't know whether any of you are acquainted with the very interesting experiments carried

out by the Western Electric Company in America. They wanted to find out to what extent various environmental factors affected output. They had a special room constructed and fitted up in exactly the same way as the girls' usual workroom. They experimented with different conditions of lighting, temperature, ventilation, etc., and the output from the girls went up. They then restored the old conditions of lighting, etc., but the output still kept up. What was the cause of the increase? They got into conversation with the girls, who said that they were more interested in their work because they felt someone was taking an interest in their activities. They also said that under the experimental conditions they could work better because they were away from the bullying of the foreman, "But," they were told, "the foremen are never heard bullying the girls." "No," was the reply, "but they look it"; and it was proved that the atmosphere created by the foremen had a deterrent effect. The experimenters then got a number of workers together who were known to be fairly well respected. They were told to speak freely, that they would not be penalised, and as a result of questioning some astonishing disclosures as to the workers' attitude towards foremen and supervisors were made. The next step taken was to get a meeting of foremen and supervisors. At first, of course, these were quite annoyed and used a lot of arguments to prove the workers all wrong, but eventually they realised that their commands were often misinterpreted by the workers. Meetings were arranged for periodical discussion of various points, and as a result output was improved. That experiment was carried out over a period and it proved definitely that supervision has a very great effect on output. Some foremen have the gift of leadership and can get the best out of their workers without irritating them. Others, less good at managing people, tend to use bullying methods. When things go smoothly their methods may work well; but if there is a sudden rush of work or if things get thrown out of their normal course, I think you can soon see which comes out best. I have been in a factory which was really badly managed, but where good work was nevertheless turned out. I found that the workers were full of enthusiasm and were really doing twice as much work as they need have done if the factory was properly arranged, and that this excellent co-operation was mainly due to the one man at the head. I have had a very wide experience of firms and I can generally tell when I meet the Commissionaire at the door the type of reception I am going to get from the director and manager of the factory. The men at the head in industry have an extraordinarily important position—far more important than they realise. The head of a department has a similarly important position in his own department. I think much could be done in regard to the better selection of foremen. The usual method is

about as poor as it could be. Because he is good at dealing with material things, he is given a totally different job, that of dealing with human beings, and very often a good workman is turned into a bad foreman. I consider the selection of foremen is one of the key problems of industry.

With regard to discipline I am in favour of discipline, and workers like it if it is just. With regard to the contentment of the workers I think that has already been answered. The cutting of rates is extraordinarily difficult. There are times when some rates are obviously very "fat," and there is a temptation to cut them, but it is always a dangerous thing to cut rates. In one factory the Institute improved output so much that the workers earned one third more, and they voluntarily asked for a modification in rates. They felt they were really earning more than they were entitled to. I don't think that happens very often, but it is an actual instance of what can be done with the right spirit.

MR. GORDON: What is the effect of noise on the worker, as regards output and concentration on his work? Has the Institute of Industrial Psychology been called in by the Japanese millowners and the results of their investigations applied in their mills? With regard to the improvements talked of, it seems to me the production engineer could well make a study of economics. I think that with the increased leisure of the worker, he will develop wider interests, and these interests will develop hobbies; hobbies develop crafts and other industries might spring up as a result. I think the development of wider interests by the worker during his leisure coupled with increased leisure for the worker is bound in turn to assist in the development of other industries.

DR. MILES: Investigations into the effects of noise have not been entirely conclusive, but our general conclusions are that noise has a bad effect on work which requires concentration, but that it has little effect on purely physical or manual work. We can adapt ourselves to noisy surroundings with astonishing rapidity. When one first goes into some factories, one is conscious only of a continuous din, but after an hour or so one hardly notices the noise. It is much easier to get used to a continuous background of sound than it is to loud, intermittent and irregular noises. This last sort of noise is distracting and irritating. If the noise is too loud, partial or complete deafness becomes common. The hearing of riveters and boilermakers, for example, is often impaired by the noise of their work. Ear-plugs are valuable in such work, but they must fit the men's ears properly. This is a point which is often overlooked, with the result that the men don't use them. In an investigation in an inspection department we came across another effect of noise. There was so much noise from the adjoining departments that you could scarcely hear yourself speak. We suggested

several improvements in the methods of inspection, and the firm then fitted up another small building in which we could put some of the men from the inspection department, and in which we could try out our ideas. At the end of a fortnight we had obtained a 36 per cent. improvement. We would have obtained 50 per cent. but for one fault—the new department was so quiet that the workers could carry on long and interesting conversations, whereas in the old inspection department the noise was so bad they had to carry on with their job.

We have not been called in by the Japanese millowners, but they are very interested in industrial psychology. About eight years ago we had a Japanese doctor who had been to the States, and came on over here to see what we were doing with the idea of setting up a similar organisation in Japan. In Russia they are going into the question very thoroughly. I was there a couple of years ago, and it is extraordinary how they are developing the matter there. They are definitely giving it much more attention than we are. When I got back to England I felt that we were only just beginning work. Of course, we shall have to judge by results, but the first intention is right enough. I went into the Institute of Industry at Moscow. They have a whole lot of machines arranged. The workers were required to carry out rest pauses and correctional pauses. A man who had to look or bend down at his work and had to do certain physical exercises calculated to correct the bending. I should have thought that it would have been better to build the machine to give the worker a better position. With regard to that, some of the machines I saw this afternoon were not very well designed in that respect; the position of the operator was not too good from the point of view of good work. If you were going in for a rifle competition or playing billiards, you would select the easiest position you could get. I sometimes think I would like to condemn the designers of some machine tools to two years labour on their machines on a very tight piece rate—it might make them realise the point of view of the workman.

A cordial vote of thanks to Dr. Miles for his lecture was adopted.

The Institution of Production Engineers.

Rules and Syllabus of the Graduateship Examination.

Objects of the Institution.

Among the objects for which the Institution is established are :—

" (a) To promote the science and practice of production engineering ; and for that purpose to carry out any of the following objects :

(b) To hold meetings of the Institution for reading and discussing communication bearing upon the said science and practice, or the application thereof, or upon subjects relating thereto.

(c) To enable engineers to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of the practice of production engineering, and the publication and communications of information on such subjects to members of the Institution and others.

(d) To establish scholarships, organise lectures, hold examinations, to grant premiums and prizes for papers and essays, and by any other similar means to enlarge the knowledge and improve the practice of production engineering."

Qualifications for Graduateship.

As defined in the Articles of Association the qualifications for Graduateship are :—

" Graduates shall be persons, not under twenty-one years of age, who can show evidence that they are receiving practical training in production engineering, and who have passed an examination prescribed from time to time by the Council, or who otherwise satisfy the Council that there are special circumstances which, in the opinion of the Council, entitle them to admission.

Graduates may not continue as such if they cease to follow the professional calling of production engineering, nor in any case beyond the age of thirty ; they may, however, between the ages of twenty-eight and thirty be transferred, on application, at the discretion of the Council, to the class of Associate Members.

Candidates for admission as Graduates who have passed the aforementioned examination but who have not yet attained the

age of twenty-one, may attend the meetings and receive the publications of the Institution without charge, but shall not be entitled to vote at meetings or be entered in the Register of Members; but on attaining the age of twenty-one they may apply to be admitted as Graduates, and upon being so admitted shall have their names entered on the Register and become Members of the Institution.

No person shall be elected a Graduate after the completion of his twenty-ninth year."

The Annual Subscription for each Graduate is £1 up to twenty-five years of age, and £1 10s. between twenty-five and thirty. On admission to the Institution Graduates may be required to pay an entrance fee, the amount of which shall be determined by the Council from time to time. At present, and until further notice, no entrance fee is charged.

Sir H. Austin Prize and Free Graduateships.

In addition to the Sir Herbert Austin Prize awarded to the candidate of highest attainments, the Council of the Institution will award Free Graduateships up to twenty-five years of age each year to those eligible candidates who attain the five highest places in the Examination.

Examination Conditions.

Examinations will be held each year on the Friday and Saturday following Easter Sunday, in London, Glasgow, Birmingham, Manchester, and Bristol, and also at any approved University, Technical Institution or Works School elsewhere as may be required. Where less than five candidates enter at any centre for the examination, a local fee, additional to the ordinary examination fee of 10/-, may be charged.

Candidates are required to fill up the prescribed Form of Application for admission (which can be obtained on request from the Head Office of the Institution, or from the Hon. Secretary of any Section of the Institution) and to send the form, together with the examination fee of 10/- to the General Secretary not later than 31st January. Where permission to sit for the examination is not given, the examination fee will be returned.

The examination will be divided into five sections. Work on the first section—an Essay—will be performed at home and must be submitted by the date which will be announced, whilst the remaining sections will be covered at an examination centre.

The examination will be of six hours' duration each day with an interval of one hour and a half from 1-0 to 2-30 p.m., but candidates must present themselves not later than 9-45 a.m., at the place of examination on the Friday morning.

Candidates must provide themselves with drawing instruments, scales, and set squares at examinations during which they may be required. Four-figure Logarithmic Tables and squared paper will be provided by the Institution. No other books or instruments may be carried into the examination room. Slide Rule calculations will be accepted throughout.

The list of successful candidates will be printed and posted to each candidate between one and two months after the examination. No other examination certificate will be issued.

SYLLABUS.

The following Syllabus for the various sections of the examination is given to indicate the lines of study recommended to candidates, and is not intended to limit their interests but to direct them in desirable lines.

A general knowledge of the subjects is expected and the questions should not be beyond the capabilities of those who have taken an inquiring interest in their chosen profession, although their experience is of necessity limited.

The Papers of the Graduateship Examination are intended to test the candidate in those special branches which are of peculiar importance in Production Engineering. In evaluating the candidate's work, the examiners will be guided rather by the practical knowledge and interest shown than by an academic reproduction of text-book information.

The Council of the Institution feel that although one of the major problems of Production Engineering is that of the human factor involved in the relations between Capital, Management, and Labour, too little attention has been given to this important subject in the Curriculæ of Technical Schools. In certain Papers, therefore, some questions will be framed not only to reveal the candidates' attitude towards their fellow-workmen, but to discover their mental attitude towards Industry in general and Production Engineering in particular.

Essay.

Candidates whose Application Form has been accepted will be required to submit an Essay of from 1,000 to 1,500 words on a Production Subject, within four weeks of the despatch of such notification. A list of Subjects will be supplied. Works of reference may be consulted by candidates, *the titles of such works should be stated*. The Essay must be accompanied by a Declaration that, subject to the consultation of works of reference, it is the unaided work of the candidate.

FIRST DAY.

Section A.

ONE only of the three following subjects is required to be taken :—

(1) **Construction of Machine Tools and Jig and Tool Design.**

Time 3 hours (10-0 a.m. to 1-0 p.m.).

Machine Construction.

Knowledge of construction of standard and well-known special machine tools, including typical constructions for wear

adjustments, convenience of controls, disposal of swarf, protection of parts from swarf and dirt, ease of cleaning and lubrication, feed mechanisms, and capacity of machines.

Ability to make sketches illustrating details of construction and to show, by written descriptions aided by sketches, an intimate knowledge of how the machines and their parts function.

Geometry and calculations relating to simple mechanisms and jigs.

The principles of alignment tests for spindles, slides, and other machine tool elements.

Layout of radial and axial cams and former bars.

Capacity of clutches and power transmission elements.

Selection, Installation, and Maintenance.

Selection of standard and special machine tools for required operations.

Methods of testing the alignment and accuracy of machine tools, acceptance tests, including production times.

Methods of supporting, fixing, and levelling of machine tools. Design of foundations where necessary. Layout of machine tools for required sequence of operations.

Care and maintenance: Cleaning, lubricating, overhauling, and adjusting for wear; belting, belt striking and other control gears; coolants and cooling systems; compressed air auxiliary services.

Tools and Equipment, Jigs and Fixtures.

Cutting tools, their shapes and angles for different cutting tools and the materials to be cut, variation with type of operation; turning, planing, drilling, boring; drilling tools and boring bars, reaming tools, pilot reamers, broaches. Holding and support of work and tools, tool holders.

Design and construction of jigs and fixtures, fabrication by welding, methods of work location and clamping, jig boring to accurate dimensions and testing of jigs, bushes.

British standard and other small tools and cutters.

(2) Physical Metallurgy and Treatment of Metals.

Time 3 hours (10-0 a.m. to 1-0 p.m.).

Cast Iron and Steel.

Pig iron and the production of : (*a*) common grey iron castings; (*b*) malleable iron castings; (*c*) wrought iron; (*d*) steel by the various processes. Composition and general properties of those and of the principal steels used in engineering. Effect of alloying elements in steel and the selection of steel for the special properties required. Machinability.

Non-Ferrous Metals and Alloys.

General properties and uses of the principal non-ferrous metals and their alloys, brasses, bronzes, aluminium and magnesium alloys, bearing metals, and solders.

Primary Forming Processes.

General description of Foundry Practice, common methods of moulding and procedure in casting as applied to cast iron, steel castings, and non-ferrous metals. Special foundry methods, such as die-casting, centrifugal casting. Methods for quantity production. Cold and hot working of ferrous and non-ferrous metals. Fabrication by welding, acetylene and electric welding, rods and fluxes used, tests of welds.

Heat and Heat Treatment.

Methods of measuring furnace temperatures. Types of furnaces employed and their applications. Normalising, annealing, quenching, tempering, case-hardening. Critical thermal points and their determination, application to heat treatment of steels and non-ferrous metals. Heat treatment of large forgings and castings. Heat treatment of non-ferrous metals.

Structure of Metals.

Use of microscope in examining structure, relation of structure to mechanical properties, recognition of various constituents in iron and steel and the simple non-ferrous metals. Effect on structure and properties of hot and cold working and heat treatment.

Testing of Materials.

Tensile, compression, torsion, and impact tests. Cupping tests. Various hardness tests, scleroscope, Brinell, Vickers, and Rockwell. Tests for work hardening. Effects of high temperature on strength and other properties. Hot hardness of carbon and high-speed tool steels.

Cutting Tools.

Special properties required in cutting tools, the various tool steels, composition and treatment, special alloy cutting tool.

(3) The Application of Electricity to Production.

Time 3 hours (10-0 a.m. to 1-0 p.m.).

(*Note.—It is expected that candidates will have some knowledge of the underlying principles before embarking on the following course*).

General characteristics of D.C. shunt and series motor and A.C. induction motors; Starting torques and stalling torques; Methods of starting and speed control. Losses in Electrical

machinery: losses in efficiency and H.P. equivalent. Electric motor drive: choice of motor; Individual and group drives. Economics of electrical drives.

Illumination: Candle power: Mean spherical candle power; lumen output; foot-candle. Electric lamp efficiencies; Electric lighting system efficiencies. Types of reflector used. Spacing-height ratios: Utilisation Factor; Electric lamp economics: Effect of increased illumination on work output.

Electric Furnaces: Types of furnace; advantages of electric furnaces: Temperature measurement and control.

Electric Welding. Arc welding with bare and covered electrodes: A.C. and D.C. arc welding layouts. Resistance welding. Electro-deposition of metals—description of process and equipments.

Electrical Tariffs. Reasons for various tariffs explained. Effect of demand, diversity and load factors on Electrical Power economics.

Effect of Power Factor. Methods of P.F. improvement.

Home Office Electricity Regulations: The more important of these should be known.

Section B.

Workshop Practice and Processes.

Time 3 hours (2-30 p.m. to 5-30 p.m.).

Workshop Drawings. Correctly dimensioned free-hand sketches.

Modification of designs of simple articles to facilitate production.

Limit Systems, Gauges and Gauging.

Machine Tools and their uses.

The design of cutting edges.

Feeds and Speeds.

The planning and sequence of operations.

The influence of quantities upon methods of production.

Applications of Jigs and Tools.

Simple applications of Metallurgy and Heat Treatment to Workshop Processes.

SECOND DAY.

Section C.

Factory Organisation.

Time 3 hours (10-0 a.m. to 1-0 p.m.).

Works Sites.

Suitability of land for buildings and layout.

Transport facilities.

Power supplies.
Local government bye laws, rating conditions.

Buildings and Plant.
General layout as determined by nature of work.
Flow of material, arrangement of shops to suit sequence of operations.
Internal transport.
Lighting, heating, ventilation, and sanitation.
Electric power, gas, compressed air.

Equipment.
Consideration of plant according to product, variation in type depending on quantity. Lifting and transporting equipment.

Management.
Evolution of industrial management, principles of scientific management.
Types of factory organisation, organisation charts.
Factors necessary for co-ordination of office and works.
Elimination of waste.
Home Office regulations.
Workmen's Compensation Acts.

Staff.
Labour Bureau and selection of operatives.
Schemes of training for youths and apprentices.
Comparisons of various systems of remuneration, day, piece, bonus, profit sharing.

Design, Inspection, and Research.
Drawing Office organisation, specifications, component and assembly lists. Manufacturing and inspection standards, tolerance and limits, inspection at various stages, handling of rejects. British Standards, internal factory standards. Research and experimental departments.

Section D.

Planning, Storekeeping, and Costing.

Time 3 hours (2-30 p.m. to 5-30 p.m.).

Production Planning.
Organisation of a planning department, manufacturing programmes. Layout of operations, job, batch, and repetition work.
Tool layouts and capacities of machine tools, power absorbed, feeds and speeds.
Economic use of jig and fixtures.
Time and motion study, rate fixing. Work labels, job tickets, time sheets, layout cards.

Tool room and tool room machines, tool stores, issue of tools and jigs.

Care, checking, and maintenance of gauges.

Production Control.

Functions of progress department, maintenance of supplies, maintaining scheduled programmes, progress charts and indicators.

Purchase.

Materials control and stores. Market forms of metals, alloys, and other materials: Costs, specifications. Routine of issue of order and receipt of goods, checking specification and quality. Maximum and minimum stocks, price curves. Layout of stores, store keeping systems, records.

Costing.

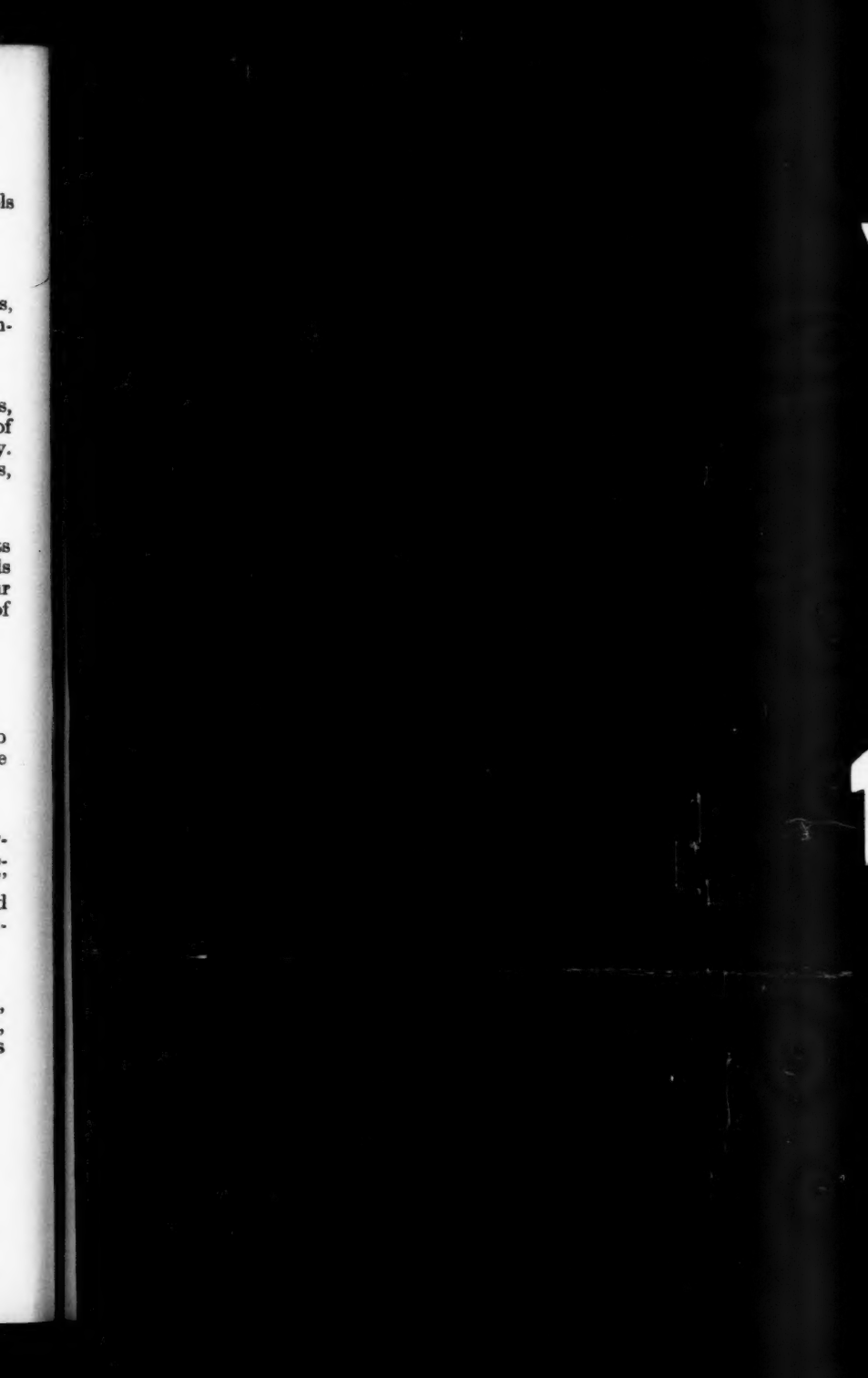
Prime costs, wages and materials. Depreciation. Oncosts and overheads and their allocation. Record of costs. Methods of time recording. Estimating production times, costs of labour and machine charges. Calculation of weights. Preparation of quantities and estimates for a quotation. Charts and graphs.

Forms of Application.

Intending candidates should apply to the General Secretary to the Institution, or to the Hon. Secretary to any Section of the Institution, for the necessary Entry Forms.

Exemption from Examination.

Candidates who have passed Section C of the Associate Membership Examination of the Institution of Mechanical Engineers, together with "The Fundamentals of Industrial Administration" in Part 2, Section A, of the same examination, or any approved examination of equal standard, will be exempt from this examination.

Copies of Examination Papers.

Copies of the latest available Examination Papers can be obtained, price 3d. per set, on application to the General Secretary, **The Institution of Production Engineers, 40, Great James Street, London, W.C.1.**